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THE COASTAL MORPHOLOGY AND SEDIMENTOLOGY OF EASTERN LANCASTER SOUND AND NORTHEAST BAFFIN ISLAND: A STUDY OF SHORELINE SENSITIVITY TO A POTENTIAL OIL SPILL

PATRICK McLAREN
WILLIAM B. BARRIE

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Fieldwork on Borden Peninsula, north Baffin Island. Steep unconsolidated bluffs are eroding to form a predominantly gravel beach. The irregular nature of the beach is the result of ice foot deposits which are being reworked by waves at the onset of the open water season. GSC 203127-J

Critical Reader

Peter Lewis

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THE COASTAL MORPHOLOGY AND SEDIMENTOLOGY OF EASTERN LANCASTER SOUND AND NORTHEAST BAFFIN ISLAND: A STUDY OF SHORELINE SENSITIVITY TO A POTENTIAL OIL SPILL

Abstract

The coasts of eastern Lancaster Sound and northeast Baffin Island may be vulnerable to the effects of an oil spill should offshore drilling take place. Effective protection and cleanup strategies must follow pre-established priorities. To provide the physical environmental information necessary for future contingency planning, the coast was mapped with respect to (i) slope, (ii) glacier, rock or unconsolidated coast, (iii) type and sedimentology of the beach and (iv) nature of the intertidal zone. Each of these geomorphic/sedimentologic criteria provides an indication of the coastal "physical sensitivity". This term is a relative measure of the seriousness of oil pollution in a particular environment with respect to probable dispersal of oil, residence time and cleanup difficulties. Physical sensitivity increases when (i) slope decreases, (ii) the coast is unconsolidated, (iii) a beach is present, (iv) the beach material is coarse rather than fine, (v) intertidal flats are present, and (vi) the width of the intertidal flat increases.

Empirical values allotted to each of the descriptive elements of the map legend enable each coastal map unit to be placed in an appropriate physical sensitivity category (PSC) from 0 to 10. In general, as the PSC increases, the following also increase: (i) the persistence time of hydrocarbons in the environment and hence the need for cleanup, (ii) cleanup difficulties and (iii) the potential damage to the environment by cleanup operations. The physical sensitivity maps will enable rapid determination of the environments that warrant protection whereas, if oil does pollute the coast, the descriptive maps will provide the basis for cleanup procedures.

In general, the amount of shoreline in high physical sensitivity categories (8 to 10) is small, constituting only 6 per cent of the total coast. Furthermore, the ubiquitous effects of ice in all coastal environments may significantly decrease residence time of oil through mechanical abrasion and sediment removal. Because of the small population and the difficulties of operating effective countermeasures in an ice environment, protection and cleanup will be unrealistic for anything more than small local priorities.

Résumé

Les côtes des régions est du détroit de Lancaster et nord-est de l'île Baffin sont susceptibles d'être touchées par d'éventuels déversements de pétrole, advenant la mise en oeuvre de forages au large des côtes. Afin d'être efficaces, les stratégies de protection et de nettoyage doivent suivre un ordre de priorité établi à l'avance. Pour obtenir sur le milieu physique les renseignements nécessaires à l'élaboration future de plans de mesures d'urgence, des cartes côtières ont été préparées qui mettent en évidence les éléments suivants: i) la pente, ii) les glaciers, les rochers et les parties meubles de la côte, iii) la nature et la sédimentologie des plages et, iv) la nature de l'estran. Tous ces critères géomorphiques et sédimentologiques donnent une indication de la "sensibilité physique" de la côte. Cette sensibilité constitue, pour un milieu particulier, une mesure relative de la gravité de la pollution par le pétrole, quant à sa dispersion, au temps de séjour des polluants et aux difficultés inhérentes au nettoyage. La sensibilité physique augmente, i) avec la diminution de la pente, ii) lorsque la côte se compose de matériaux meubles, iii) avec la présence d'une grève, iv) lorsque la grève se compose de matériaux grossiers plutôt que fins, v) avec la présence de terrasses intertidales et, vi) avec la largeur des terrasses intertidales.

Les valeurs empiriques attribuées à chaque élément descriptif d'une légende de carte permettent d'inscrire chaque unité des cartes côtières dans une catégorie appropriée de sensibilité physique (CSP), selon une échelle de 0 et 10. En règle générale, toute augmentation de la CSP s'accompagne d'un accroissement, i) de la persistance des hydrocarbures dans le milieu, donc de la nécessité des travaux de nettoyage, ii) des difficultés de nettoyage et, iii) des dommages possibles que les travaux de nettoyage peuvent causer à l'environnement. Les cartes de sensibilité physique permettront donc de déterminer rapidement les milieux où la protection serait justifiée, tandis qu'en cas de pollution côtière par le pétrole, les cartes descriptives fourniront les données fondamentales nécessaires aux travaux de nettoyage.

En général, peu de zones littorales sont classées dans les catégories de très grande sensibilité physique (8 à 10), ne représentant que 6% de toute la longueur de la côte. De plus, l'omniprésence de la glace dans tous les milieux côtiers peut réduire de beaucoup le temps de résidence du pétrole en raison de l'érosion mécanique et de l'enlèvement des sédiments qu'elle occasionne. Vu la faible densité démographique et les difficultés inhérentes à l'application de contre-mesure efficaces dans un milieu couvert de glaces, il serait déraisonnable de vouloir appliquer des mesures de protection et de nettoyage dans ces régions, si ce n'est en cas de sinistre local d'envergure restreinte.

INTRODUCTION

Background and Objectives

Lancaster Sound and western Baffin Bay is a region of high oil and gas potential (Fig. 1). Exploratory drilling is proposed in water depths ranging from 380 to 850 m and operations are possible only during the open water months of July, August and September (Petro-Canada, 1979). Frequent occurrence of icebergs, deep water, and a short drilling season increase the probability of a blow-out which is estimated at 1 in 1000 to 1 in 10 000 (Milne and Smiley, 1978). Tanker traffic may also increase as demands for refined oil products for Arctic development and/or transportation of crude oil from northern discoveries to southern markets evolve. This region, known to be a highly productive maritime environment, is therefore potentially subject to the effects of an oil spill, originating from either a well blow-out or a tanker disaster.

In preparation for the possibility of such a disaster the Geological Survey of Canada, supported by Petro-Canada and the Environmental Protection Service, Environment Canada, undertook an environmental coastal study in order to:

- define the physical environments on the coasts of eastern Lancaster Sound and northwest Baffin Bay;
- assess the coastal vulnerability[1];
- assess the coastal physical sensitivity[2]; and
- suggest protective measures and cleanup procedures for each environment.

This report and the accompanying maps follow closely the format and concepts already established for the coast of Labrador (McLaren, 1980), and are designed to provide the physical information required for oil spill contingency planning of the coasts in this region.

Previous Work

Few site specific coastal studies have been undertaken in eastern Lancaster Sound and northwest Baffin Bay. Previous research focused on Radstock Bay, Devon Island (Owens and McCann, 1970; McCann, 1972, 1973; McCann and Carlisle, 1972; McCann and Owens, 1969, 1970), northern Somerset Island (Taylor, 1975) and eastern Melville Island (McLaren, 1982). With the potential for hydrocarbon development in this area several environmental overviews have been completed. Owens (1977) provided a synopsis of Arctic coastal environments and discussed the effects of littoral processes and coastal geomorphology on oil spills. Milne and Smiley (1978) have briefly discussed coastal morphology, processes and cleanup possibilities. In more detail, Barrie et al. (1978) have mapped the coasts of Lancaster Sound as far east as Navy Board Inlet with respect to slope, geology and geomorphology as an aid to marine terminal planning. These maps are also included in a Lancaster Sound data atlas (Department of Indian and Northern Devlopment Affairs, in press).

Another atlas overview (Canada, Fisheries and Environment, 1978) for the whole arctic has provided background information for developing oilspill countermeasures. Both a coastal geomorphology map and a resultant "contamination rating" are included but at a scale too small (1:15 million) for practical use. An initial environmental assessment by Petro-Canada (1979) included a description of coastal environments in greater detail than all previous studies. Coastal maps being prepared by Petro-Canada for an environmental impact statement will use a similar legend to that developed in the Labrador coastal study (McLaren, 1980) which is also utilized in this report.

Field Methods

Field work was conducted between August 17 and September 21, 1978, from the **M.V. Gulf Star**, an ice strengthened ship of 544 gross tons and length 44 m. McLaren et al. (1981) provide a full description of the coastal program in which all data from selected coastal sites are presented (Fig. 1). These include beach profiles and sediment analyses from both beach and nearshore environments, selected photographs and a sequence of nearshore maps illustrating bathymetry, sidescan sonar recordings, sediment texture, biomass, abundance of organisms and species associations. The biological component of the study was undertaken by LGL Ltd. and is reported in Thomson et al. (1979). In addition, a nearly continuous sequence of oblique airphotos were taken from altitudes varying from 60 to 300 m (Fig. 1). These photos were subsequently used for the identification and mapping of the coastal environments.

Acknowledgments

This project was initially conceived by G.H. Jones, then of Petro-Canada, and shared jointly among Petro-Canada, the Geological Survey and the Arctic Marine Oil Spill Program (AMOP) of Environment Canada. The support of S.I. Ross and other AMOP members is gratefully acknowledged. Appreciation is expressed to Petro-Canada for providing additional personnel and field logistics.

Particular thanks are due to J.M. Sempels and R.A. Sieffert who provided capable support to all aspects of the project. We also extend our appreciation to D.H. Thomson and to the other participating scientists from LGL Ltd. who cooperated in a successful liaison with the geological half of the study. W.E. Markham generously allowed the use of his ice maps for inclusion in the report. The support of Polar Continental Shelf was instrumental in flying and photographing the shoreline. The efforts of Captain M. Whalen and the crew of the **Gulf Star** were largely responsible for the successes of the field season.

Critical reading by C.P. Lewis and J.L. Luternauer aided considerably in grammatical and scientific clarification of the text.

PHYSIOGRAPHY

Davis Highlands

Most of the study area falls within the Davis Highlands physiographic region (Fig. 2). Precambrian crystalline rocks occur throughout the area and form an irregular and rugged landscape dominated by ice erosional features, particularly fiords. On deglaciation, isostatic recovery has been as much as 100 m (Miller and Dyke, 1974) resulting in numerous raised shoreline features such as uplifted deltas and beaches. At present, extensive permanent ice fields cover much of the eastern margin of the study area. The largest ice fields occur on Devon and Bylot Islands and tidewater glaciers discharge into Lancaster Sound, Baffin Bay, Pond Inlet and Navy Board Inlet.

Southeast Devon Island

Along the Lancaster Sound coast, the region is characterized by steep cliffs which rise to elevations exceeding 900 m less than 2 km inland. Three glaciers flow from the Devon Icecap into the sound between Cape Warrender and Cape Sherard. Associated with these are

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[1] Vulnerability is defined as the susceptibility or the likelihood of oil in the offshore reaching coastal environments.

[2] Physical sensitivity is a relative measure of the seriousness of oil pollution in a particular environment with respect to probable dispersal of oil, residence time and cleanup difficulties. The term might be considered as part of a "total sensitivity" which takes into account all aspects of damage due to oil pollution.

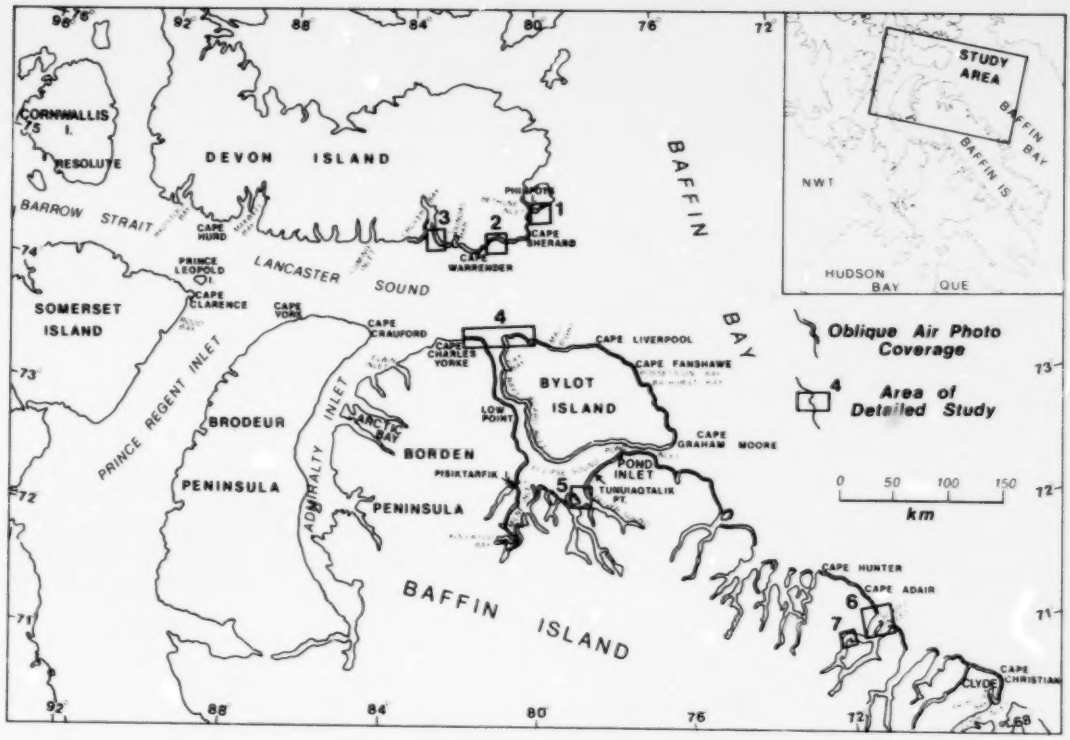


Figure 1. *Location of study area and place names used in text. Shaded areas indicate regions of high hydrocarbon potential (Dept. of Indian and Northern Affairs, 1980).*

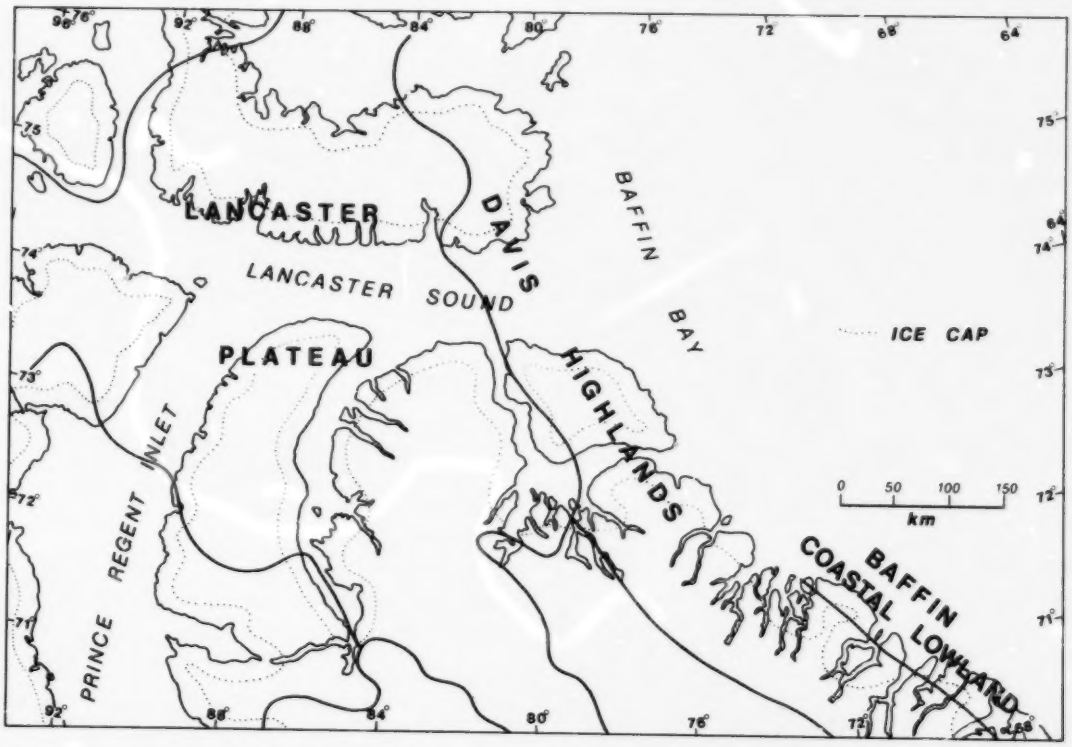


Figure 2. *Physiographic regions (after Bostock, 1970).*

extensive lateral and medial moraines and outwash deposits. A 12 km wide lobe of the icecap extends into Baffin Bay almost isolating Bethune Inlet.

The region north and east of Cape Sherard including Philpots Island, although part of the Davis Highlands, contains the only extensive lowland area in eastern Devon Island. Elevations are normally less than 100 m and the area is covered with a thin veneer of surficial materials. Beaches on the southeast coast of Devon Island are discontinuous, narrow, and usually grade into bluffs and rocky headlands. Boulder beaches occur on Philpots Island but gravel and sand beaches are predominant elsewhere.

Bylot Island

The Davis Highlands area of Bylot Island is underlain by a complex of highly metamorphosed crystalline rocks (Jackson and Davidson, 1975) which form the Byam Martin Mountains. These mountains are predominantly ice covered and glaciers flow down on all sides, occasionally breaching the shoreline. Within the highlands there are two major lowland regions. The first forms the northwest corner of the island and is characterized by low rolling hills with an almost continuous gravel beach here and there backed by low eroding bluffs. Adjacent to Lancaster Sound, the coast changes to a series of rocky headlands with low cliffs and bluffs bordered by a wide gravel plain containing traces of raised beaches.

The second lowland region extends along the northeastern Bylot Island coast from Cape Fanshawe to Maud Bight. Less than 100 m in elevation, it is dissected by numerous small streams and rivers. With the exception of three diabase dykes west of Cape Liverpool that have formed rocky headlands, gravel and cobble beaches are continuous, backed in some areas by eroding bluffs.

South of Cape Fanshawe the coast changes to cliffs and steep rocky headlands which are broken by three broad glacial valleys. These contain braided streams and have formed extensive outwash plains which terminate at the coast producing wide gravel and cobble beaches. The rocky nature of this shore continues into Pond Inlet where mountains reach elevations of over 1300 m within 2 km of the coast. Beaches, when present, are composed of cobbles and boulders.

Northeastern Baffin Island

Formed principally in the Davis Highlands (Fig. 2), the region between Eclipse Sound and Pond Inlet is a low lying coastal plain whose elevation is less than 150 m. West of Tunuiaqtalik Point the shore is low and rocky with numerous pocket beaches composed of sand and gravel. East of the point, continuous sand and gravel beaches are backed by steep bluffs.

From Pond Inlet to Clyde, numerous fiords penetrate deeply into the highlands. Although low at their entrances to Baffin Bay, the sides of the fiords are, for the most part steep and precipitous rising in places to over 400 m. Inland, elevations range between 600 and 2000 m and the mountains contain an extensive cover of permanent ice.

Lancaster Plateau

South Devon Island

West of the Davis Highlands, thick sequences of nearly horizontal Palaeozoic strata overlie Precambrian rocks forming prominent plateaux about 600 m high. Their coastal margins are marked by talus-banked cliffs which rise from a coastal plain whose width varies from 7 km to less than 100 m. A broad, flat, alluvium-filled valley extends north from the head of Dundas Harbour and the coastal plain on both sides of the entrance to Croker Bay is covered with flights of raised sand and gravel beaches (Barrie et al., 1978).

Borden Peninsula

Borden peninsula, although belonging in the Lancaster Plateau division (Fig. 2), also contains coastal plains and highlands. A broad coastal plain dominates the northern part of the peninsula and consists of a thick succession of flat lying, Palaeozoic strata overlain by a substantial thickness of drift (Craig, 1965). Extending up to 10 km inland, it has an elevation of about 150 m. Drainage is well developed and the Charles Yorke River is the largest of a number of rivers which enter Lancaster Sound through alluvium-filled valleys and form extensive deltas. The coastal plain terminates with low cliffs and bluffs which are breached by numerous ravine-like stream valleys and rise above a narrow, and for the most part, continuous gravel beach.

A highland region with elevations up to 1250 m extends from Elwin Inlet across Borden Peninsula to Low Point on the west coast of Navy Board Inlet. There are three large ice fields in the region and four glaciers flow from the easternmost one into Navy Board Inlet. The shoreline is steeply cliffed, and is generally devoid of beaches.

South of the highland region the terrain regains more of the characteristics of a plateau. It is deeply dissected by rivers and streams and has an average elevation of between 600 and 700 m. A broad coastal plain up to 20 km wide and with elevations less than 150 m extends along Navy Board Inlet to the northwestern shores of Eclipse Sound. This river has an extensive delta and tidal flats extend for a considerable distance north and south from its mouth. Contiuous sand and gravel beaches occur along the shores of Navy Board Inlet and traces of raised beaches appear throughout the area. The shoreline is backed in some places by low, stream-dissected bluffs.

Along the southern and southwestern edges of Eclipse Sound are a series of bays, inlets and sounds which are generally steep-sided and devoid of lowlands except at their heads and where rivers have formed alluvial fans and deltas. Beaches are generally absent where sheer cliffs rise above the water's edge, although the presence of talus occasionally results in narrow boulder strandlines.

Southwest Bylot Island

Unlike the rugged topography which dominates Bylot Island, this is a region of low, rounded hills underlain by gently inclined sedimentary strata (Hodgson and Haselton, 1974). The area is dissected by a dendritic network of streams and rivers, the largest of which originate from the glaciers in the Byam Martin Mountains and have formed deltas along the shores of Navy Board Inlet. The coastline is characterized by a broad, gently sloping foreland which extends inland to elevations of less than 100 m and contains numerous raised beaches. Steep, eroding bluffs become prominent farther north along the shore of Navy Board Inlet. Beaches are composed of sand and gravel and are generally continuous throughout this region.

Baffin Coastal Lowland

Eastern Baffin Island

This low-lying region forms a margin between the outer coast and the Davis Highlands (Fig. 2). Extending up to 30 km inland, it has a mantle of marine, fluvial and glaciofluvial deposits. Low cliffs and bluffs occur along parts of the shoreline and except where cliffs and rocky headlands meet the sea, most of the lowland region is fronted by a continuous sand beach.

COASTAL VULNERABILITY

Introduction

Considerable effort has been directed towards predicting the probable locations where oil may reach the shoreline. Milne and Smiley (1978) estimated that during the open water season, a blowout at the proposed Norlands Dundas K-56 drilling site (74°05'N, 81°10'W) will result in maximum contamination (14% by volume assuming a blowout volume of 950 m^3/day) on the north and east coasts of Bylot Island. Some oiling is predicted on the shorelines of Navy Board Inlet and Eclipse Sound (3% by volume) with minimal contamination occurring along south-central Devon Island (0.5%).

Milne and Smiley (op. cit.) suggested that during breakup (May, June and July) landfast ice will prevent oil from entering Navy Board Inlet as well as the bays along north Bylot and south Devon islands. During freezeup (October to December) oil may become incorporated into landfast ice but much of the oil is predicted to move with drifting ice out into Baffin Bay. Between December and April, the oil will collect under the ice and move out of Lancaster Sound into the stream of ice drifting south in Baffin Bay. For a one-year period of continuous oil pollution from a blow-out, they have predicted that about 6% of the total volume discharged will contaminate the southeast margin of Lancaster Sound.

Fenco (1978) approached the problem of predicting the fate of oil from a blowout at the Dundas K-56 drill site using both slick rose modelling and trajectory modelling. The latter, when applied to open water conditions, identified some trajectories reaching the north and northeast coast of Bylot Island but most trended east and south into Baffin Bay missing the coast altogether. In the presence of landfast ice extending 16 km from shore, the model predicted total impact of oil with the ice edge.

The Fenco report suggested that oil slick motion is principally determined by the pattern of residual currents (i.e., currents due to atmospheric pressure fluctuations and variation in density of the water mass) with winds providing only minor variations in trajectory. A slick rose model using wind data (August and September, 1977) from Cape Charles Yorke (Fig. 1) and estimates of residual surface currents identified Navy Board Inlet and the northwest and north-central coasts of Bylot Island as areas of potential contamination by oil.

Another trajectory model examined the effects of hypothetical releases of oil from four potential drill locations in Lancaster Sound during ice free conditions (Marko, 1979, in press). The simulations indicated that serious shoreline pollution is almost inevitable under the influence of north, south and east winds.

Although fate and behavious of oil spilled on water has been studied for at least the past ten years, Mackay (1978) suggested that spill modelling is still in an immature stage of development. He concluded that such studies can play an important role in minimizing the environmental effects of oil spills but that "we are really in the position of having rather poor input data, manipulating it by a series of doubtful equations and giving results which (not surprisingly) rarely agree with actual observations and are certainly inadequate for the consumer". In this report there is a basic assumption that oil will reach the shoreline and the following sections focus on the separate physical parameters that will affect the manner in which it arrives.

Ice Conditions

Data Sources

The ice regime of Lancaster Sound and northwest Baffin Bay is described by Markham (1969, 1977), Canadian Hydrographic Service (1970), Marko (1977), Petro-Canada (1979) and Milne and Smiley (1978). Environment Canada (1967-1976), has published detailed annual summaries of summer sea ice conditions including mean temperatures and wind charts from 1964 to 1972. Swithinbank (1960), Lindsay (1976, 1977a) and Canada, Department of Fisheries and Environment (1978) have all produced ice atlases covering the entire Arctic region. Markham (in press) has assembled what is probably the most comprehensive ice atlas using from 8 to 16 years of data and depicting the best, worst and median conditions on a weekly basis from mid-May to the end of October. The following description of ice conditions is drawn from all of the above data sources.

Breakup

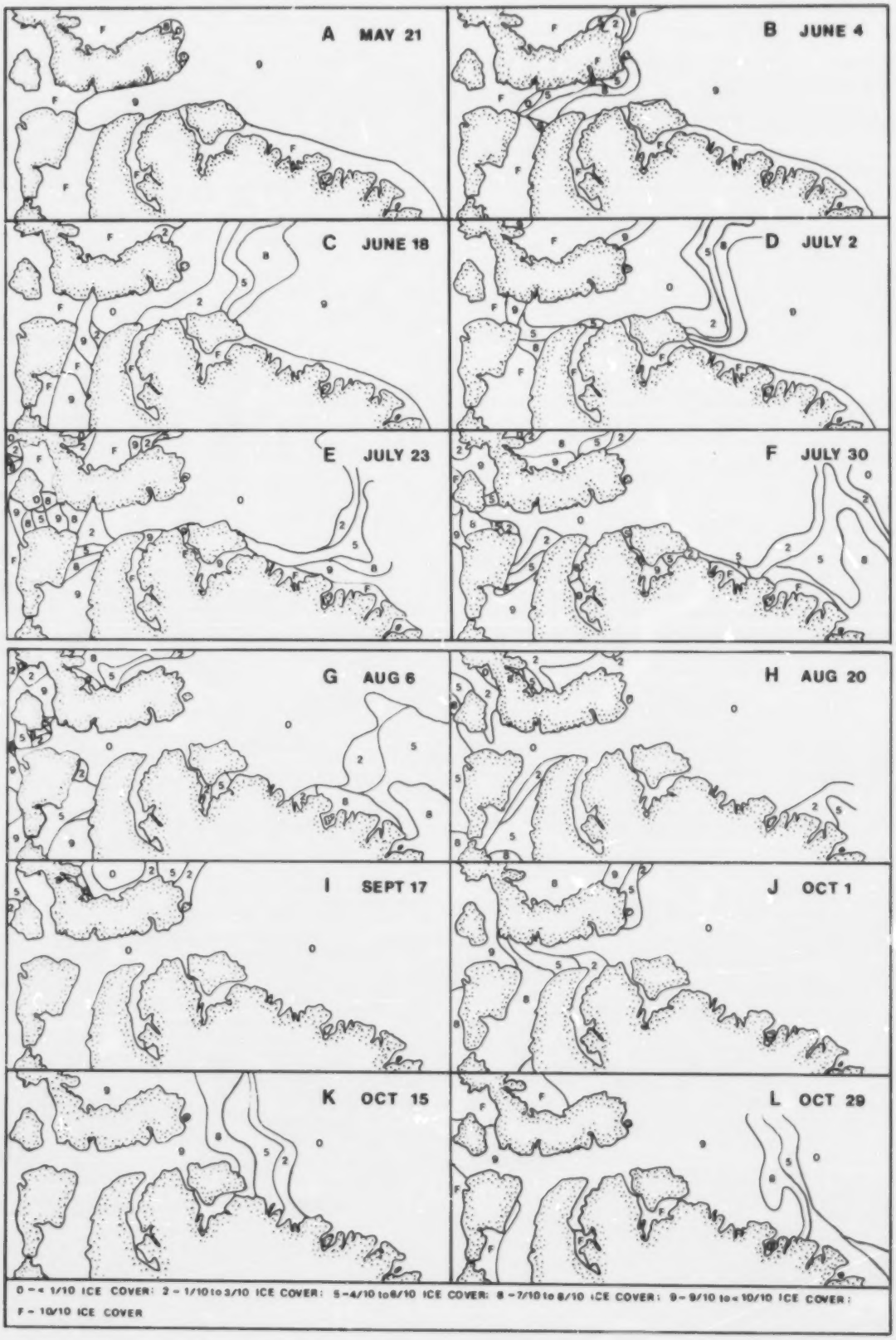
During winter, the growth of new ice reaches to about two metres in Lancaster Sound and Baffin Bay. New growth usually stops by mid-May (Fig. 3A) and breakup is initiated by rising temperatures and the expansion of the North Water, a polyna in northern Baffin Bay. During this southward expansion, which reaches Lancaster Sound by mid-June, a combination of winds, tides and currents encourages the eastern migration of ice out of Lancaster Sound creating an open water area at the junction of Barrow Strait and Lancaster Sound (Fig. 3B). Clearing is further assisted as the extension of the North Water enters eastern Lancaster Sound (Fig. 3C).

Ice atlases for the period 1961 through to 1974 show open water conditions (less than 1/10 ice cover) in Lancaster Sound by the end of June for 10 of the 14 years (Lindsay, 1976, 1977a). Earliest open water occurred in the second week of June and the latest was attained by the last week of July (Fig. 3D).

Although Lancaster Sound may be clear of ice, adjacent bays and inlets usually remain ice-covered and narrow bands of shorefast ice cling to parts of the coast well beyond initiation of the summer open water or navigation period. Bays along the south coast of Devon Island such as Dundas Harbour and Croker Bay normally clear from south to north with open water appearing first at their mouths. Dundas Harbour was ice-free by June 26 in 7 out of 13 years (Lindsay, 1977b), the earliest breakup occurring on June 9 and the latest on August 23. The clearing of Croker Bay is much more variable and open water conditions generally do not occur before mid-August but breakup has happened as early as June 26 (1968) or may not occur at all (1964).

In Pond Inlet, Eclipse Sound and Navy Board Inlet, melting first occurs along the shoreline and in particular at river mouths and in the bays and inlets. At the same time (about mid-July) the southward migrating North Water opens the entrance to Pond Inlet and gradually spreads westwards initiating a general breakup of ice in Eclipse Sound. During the period 1959 to 1974 the median breakup date for central Eclipse Sound was July 23 and for open water was August 13.

By late July the ice in Navy Board Inlet retreats southward and any unmelted ice drifts south into Eclipse Sound. Navy Board Inlet is generally ice-free by the third week in August (Fig. 3E, F, G). Winds and strong tidal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K OCT 15
L OCT 29
0 = < 1/10 ICE COVER: 2 = 1/10 to 3/10 ICE COVER: 5 = 4/10 to 6/10 ICE COVER: 8 = 7/10 to 8/10 ICE COVER: 9 = 9/10 to < 10/10 ICE COVER:
F = 10/10 ICE COVER

Figure 3. *Estimated median ice conditions from January to October (from Markham, 1981).*

currents drive the ice back and forth in western Eclipse Sound and in and out of Milne inlet until melting finally occurs (Canadian Hydrographic Service, 1978).

The fast ice which extends for varying distances offshore along the Baffin and Bylot Island coasts tends to breakup in June or early July leaving the fiords, bays and inlets still covered with fast but rotting ice to a line joining the outer points of the coast (Fig. 3D, E). Breakup in Patricia Bay on the northeast side of Clyde Inlet occurs at about mid-July and is normally ice-free by the end of July (Canadian Hydrographic Service, 1978a). These dates are similar for the breakup and clearing of the fiords and bays on the east coast of Baffin Island north of Clyde Inlet.

Summer Conditions

After breakup the dominant eastward drift of ice out of Lancaster Sound that occurred during breakup, shifts to a westward flow resulting in ice intrusion from Baffin Bay. Such intrusions from the east are rare beyond Cuming Inlet on the south coast of Devon Island due to a southward deflection causing ice to move to the south side of Lancaster Sound and eastward again to Baffin Bay. Some of this ice also enters Navy Board Inlet. Winds and an easterly current concentrate the ice along the south side of Lancaster Sound where eastward drift has been measured at 9.5 to 55 km per day (Ramseier et al., 1975). This drift can, however, be interrupted by the formation of large complex eddies near the intersection of the Sound with other major waterways such as Prince Regent Inlet (Ramseier et al., 1975; Marko, 1977). Ice in the form of north-south bands containing large floes can occur temporarily during summer across Lancaster Sound, notably between Cape Hurd (Devon Island) to Cape Clarence (Somerset Island) and Cape Warrender (Devon Island) to Borden Peninsula (Baffin Island) (Canadian Hydrographic Service, (1978a).

The average number of days for the open water season varies throughout the region being as little as 42 days off the northeast shore of Baffin Island and as many as 71 days in Lancaster Sound (Table 1). These estimates, however, do not necessarily reflect the length of time that oil can contaminate the shoreline. The presence of an icefoot remaining firmly attached to the coast after shorefast ice has broken up and moved away may protect the beach from an enroaching slick. In some cases the icefoot may not melt completely during summer or it may become buried by sediment and persist for years. Because the icefoot forms before freezeup and remains after breakup, the dates given for the beginning and end of the open water season do not necessarily apply to the beach zone.

Freezeup

Freezeup in Lancaster Sound and northwest Baffin Bay follows approximately the reverse order to spring breakup, but its pattern is considerably more regular. In early to mid-September, the ice cover expands southwards out of the northwestern edge of Baffin Bay (Fig. 3H, I) resulting in frequent intrusions of ice into Lancaster Sound by late September. During this time, new ice is actively forming in many regions, particularly in the bays and inlets of Devon Island, the south side of Eclipse Sound and the heads of fiords on the northeast coast of Baffin Island.

In Lancaster Sound, freezeup progresses eastward from Barrow Strait. By early October the freezing ice front normally reaches Brodeur Peninsula (Fig. 3J). As temperatures continue to fall, new ice formations are quickly consolidated and by mid-October the whole Sound is usually ice covered (Fig. 3K). The formation of offshore ice along the northeast coast of Baffin Island occurs somewhat later than in Lancaster Sound. In most years all coastal areas as far south as Clyde Inlet are ice-covered by the end of October, and by early November may extend up to 400 km offshore (Fig. 3L).

Winter Conditions

The pattern of winter ice conditions remains fairly constant from year to year. With the exception of Baffin Bay and Lancaster Sound, the bays sounds and inlets within the study area remain solidly covered by continuous, unmoving shorefast ice throughout the winter. Immobile ice is about 8 km wide around Bylot Island and 16 to 32 km on the east coast of Baffin Island. Along the shores of Lancaster Sound shorefast ice tends to parallel the configuration of the coastline and rarely extends more than 10 to 15 km offshore. Pond Inlet and Navy Board Inlet are covered by a continuous sheet of fast ice.

The pack ice beyond the shorefast ice is kept in motion by the combined effects of wind, tides and currents. Drift speeds have been measured in eastern Lancaster Sound at 11.5 to 22.5 km per day (Ramseier et al., 1975). Maximum thicknesses in undisturbed ice are reached by the middle of May ranging from 1.33 m to 1.85 m (Clyde Inlet), 1.17 m to 1.95 m (Pond Inlet), and 1.4 m to 1.5 m at the entrance to Lancaster Sound (Allen, 1977; Markham, 1977).

Wind Regime

Introduction

Wind reporting stations are sparse in the Lancaster Sound and northwest Baffin Bay region with long-term and regular meterorological observations available only for Resolute Bay and Clyde River (Fig. 4). The remaining wind roses shown on Figure 4 are based on short-term or irregular observations (Appendix I). Estimates of surface wind conditions in the study area have been inferred from Resolute data by Maxwell et al. (1980). The reliability of extrapolating wind data from Resolute to other areas has not received universal acceptance and Stepney (1977) asserts that such extrapolations are meaningless. Hill et al. (1978) found

Table 1. Median dates for the beginning and end of the Open Water Season (1964 to 1972; Lindsay, 1977a, b)

	Southeast Devon Island-Offshore	Lancaster Sound	Admiralty Inlet	Navy Board Inlet Eclipse Sound Pond Inlet	Eastern Bylot Island-Offshore	Northeast Baffin Island-Offshore
Beginning	July 16	July 13-17	Aug. 19-20	July 30	July 16	Aug. 27
End	Sept. 24	Sept. 24	Sept. 24	Sept. 24	Sept. 24	Oct. 8
Number of days	70	71	66	56	70	42

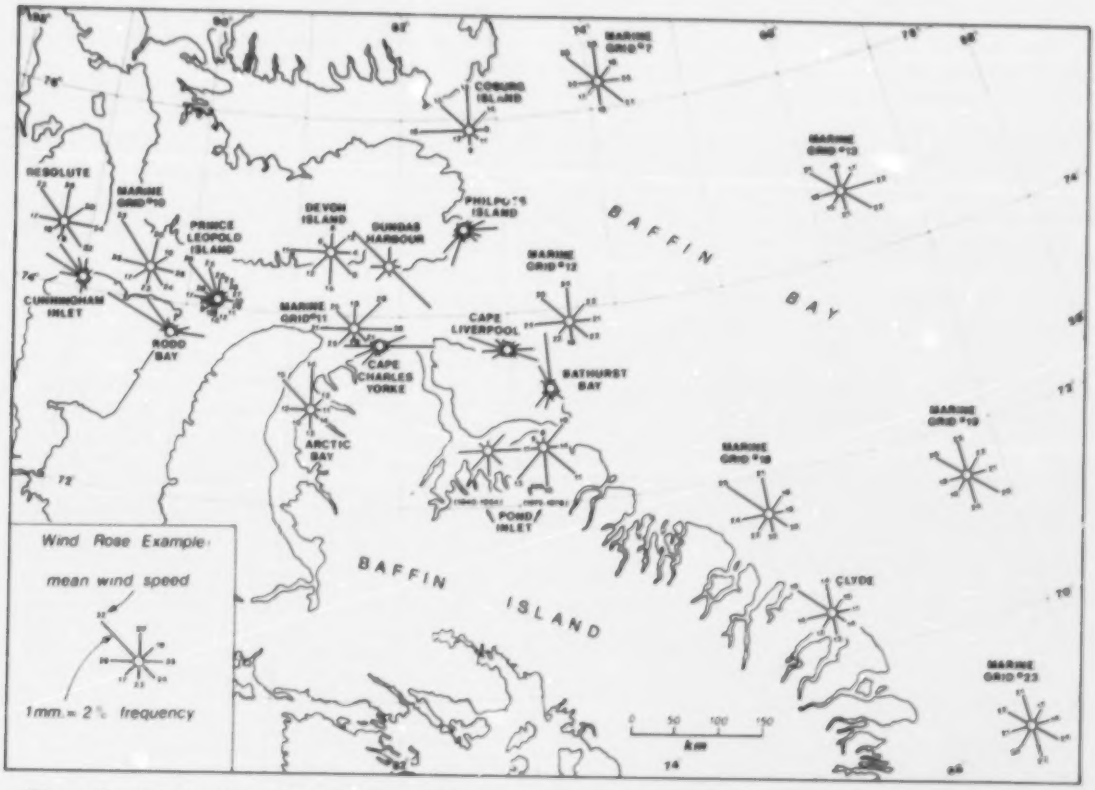

Figure 4. *Wind regime of Lancaster Sound and northwestern Baffin Bay, July to October. The data base used for the construction of the wind roses is presented in Appendix I.*

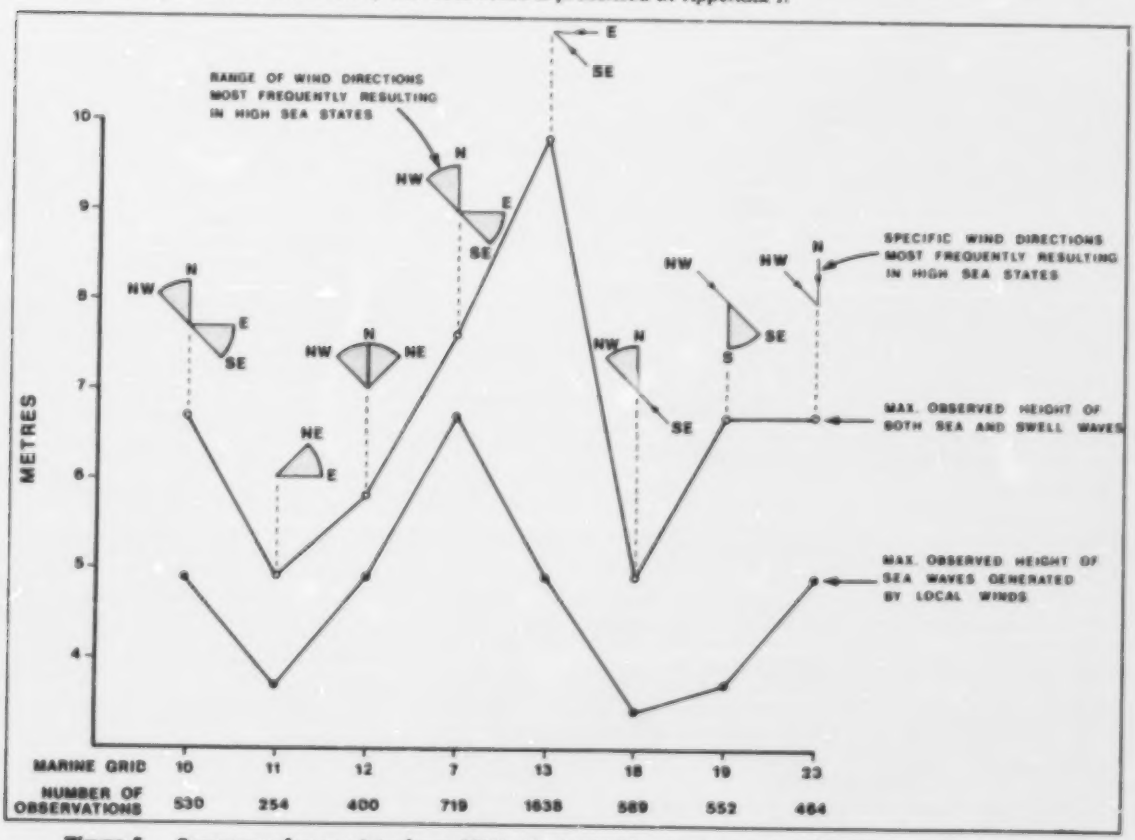
RANGE OF WIND DIRECTIONS MOST FREQUENTLY RESULTING IN HIGH SEA STATES
SPECIFIC WIND DIRECTIONS MOST FREQUENTLY RESULTING IN HIGH SEA STATES
MAX. OBSERVED HEIGHT OF BOTH SEA AND SWELL WAVES
MAX. OBSERVED HEIGHT OF SEA WAVES GENERATED BY LOCAL WINDS
METRES
10
9
8
7
6
5
4
MARINE GRID 10 11 12 7 13 18 19 23
NUMBER OF OBSERVATIONS 530 254 400 719 1638 589 552 484

Figure 5. *Summary of wave data from SSMO Marine Grids. Location of each Grid shown in Fig. 4.*

that the correlation between winds at Resolute with those in Lancaster Sound decreased rapidly with increasing distance and that the east-west components correlated much better than the north-south components. They suggested that useful predictions can be made when the influence of local topography is taken into account.

Of the data presented in Figure 4, only observations taken by ships are representative of conditions over water. All other stations are located either along the coast or a short distance inland with anemometer heights from 4 to 430 m above sea level. Coastal obstructions such as hills, bluffs and cliffs, deflect onshore winds in a direction nearly parallel to shore, usually with a subsequent increase in speed. Funnelling effects in narrowing channels such as fiords can result in twice the offshore wind speed (Fenco, 1974). For these reasons, as well as the fact that over two-thirds of the total number of wind observations represented by the rose diagrams (Fig. 4) originate from only the two stations of Resolute and Clyde, comparison between stations should be performed cautiously.

Lancaster Sound

Lancaster Sound is primarily affected by low pressure cyclones moving north into Baffin Bay from Davis Strait but also by less frequent cyclonic activity moving into the Sound from the west. Directional frequencies from Marine Grid 11 (Fig. 4) indicate that 35 per cent of all winds during the July to October period blow along an east-west axis. Frequencies from the northeast and west increase sharply in the latter half of the period. East winds tend to be strongest with a mean speed of 38 km/h followed by west and northeast winds at 31 km/h and 29 km/h respectively.

Data from Cape Charles Yorke and Cape Liverpool maintain the east-west bi-directional tendency of winds observed at Marine Grid 11. Here 70 per cent of observed winds during the open water period originate from either the west-northwest through west-southwest sector or the east-northeast through east-southeast sector (Fig. 4). At both stations westerly winds increase at the expense of easterlies in early September. The strongest winds at Cape Charles Yorke are from the east and west sectors whereas at Cape Liverpool the strongest winds are from the east-southeast to east sector and from the west-northwest.

At Dundas Harbour on the south coast of Devon Island prevailing winds are southeast during July and August and north and northwest in September and October. The winds in the latter period are strongest due to the frequent occurrence of low pressure centres in northern Baffin Bay (Headley, 1979). Katabatic winds originating on the nearby Devon Ice Cap probably form a significant portion of the observed north winds.

A duration analysis performed by the Atmospheric Environment Service (pers. comm., 1979) for July through October, 1953 to 1976, showed that winds of long duration were most frequently from the northwest and north. Long duration winds occurred throughout the July to October period but primarily during September and October. Maximum recorded durations were 172 hours from the east, 127 hours from the north and 123 hours from the northwest.

Navy Board Inlet, Eclipse Sound and Pond Inlet

The dominant influence of topography causing winds to parallel the shoreline (Woodrow, 1972) makes it difficult to extrapolate wind data from Pond Inlet, the only station in the area, to Navy Board Inlet and Eclipse Sound. Two wind roses are shown for Pond Inlet (Fig. 4; Appendix I) and refer to two sets of data; the first near sea level (1940 to 1955) and the second at 60 m elevation at the edge of a broad coastal plain (1975 to 1976). The greater frequency of winds from the south and southeast during 1975 and 1976 reflects the change in elevation of this station resulting in improved exposure to these wind directions.

From July to September the strongest winds are from the northeast and east whereas the most frequent winds are from the southwest, south and southeast. During October, winds are primarily southwest through southeast, lighter winds tending to be southerly while the stronger winds tend to blow more nearly parallel to the shoreline (Woodrow, 1972). A duration analysis performed by the Atmospheric Environment Service (personal communication, 1979) for July through October, 1975 to 1976, at Pond Inlet showed that winds of long duration were most frequently from the south, southwest and southeast. Long duration winds occurred primarily during September and October and the maximum recorded wind directions were 77 hours from the southeast and 66 hours from the south.

Northwestern Baffin Bay

Low pressure systems track into Baffin Bay principally through Davis Strait but also from the west through Lancaster Sound and from the southwest through Foxe Basin and across Baffin Island. Cyclonic activity is frequent throughout the year but an increase in activity occurs during September and October and becomes most intense during the winter months (Maxwell et al., 1980). The Davis Highlands, which stretch along the eastern seaboard, acts as a barrier to storms entering the region from the west and southwest but tend to contain storms moving north into Baffin Bay.

Wind roses for the marine grid areas in Baffin Bay and for adjacent coastal stations almost always show strong and frequent winds from the north, northwest, south and southeast (Fig. 4). During July and August, winds from the east and southeast tend to be the strongest and most frequent but in September a strong northerly flow is established and winds from the northwest and north have the greatest frequency. Mean wind speeds during September and October are between 20 and 60 per cent higher than during July and August.

Coastal stations on Devon and Bylot islands near the entrance to Lancaster Sound are affected by topography and winds blow with almost equal frequency from either direction parallel to the shore. At Clyde, trends are similar to the adjacent marine grid but mean speeds for all directions are much lower. A duration analysis performed by the Atmospheric Environment Service (personal communication, 1979) for the summer months (1953 to 1976) showed that long duration winds were most frequent from the north and northwest and appeared most likely to occur in July. Maximum recorded wind durations were 120 hours from the northwest and 78 hours from the west. Long and frequent periods of calm (i.e.: winds less than 5 km/h) have been recorded at Clyde with a maximum recorded duration of 135 hours during July.

Extreme Winds

An analysis of maximum hourly wind speeds at the stations shown on Figure 4 show a tendency to increase from July to August and decrease or remain the same in September and October (Table 2). Maximum speeds in July range from about 30 km/h in Baffin Bay (Marine Grid 12 and 23) to 75 km/h in Lancaster Sound (Marine Grid 11). In August, maximum speeds increase to about 50 km/h or higher in Baffin Bay and to 89 km/h or more in Lancaster Sound. These speeds fluctuate either slightly higher or lower during September and October.

Table 2. Maximum hourly wind speeds (km/h) recorded at stations within the study area (Fig. 4)

Station (Fig. 4)	July	August	September	October
Resolute	85	89	105	92
Cunningham Inlet	53	46		
Marine Grid 10	63-87[1]	63-87	89	89
Rodd Bay	40			
Prince Leopold Island	57	63	72	
Arctic Bay	52	52	48	72
Marine Grid 11	63-87	89	63-87	63-87
Cape Charles York		47		
Dundas Harbour	52-61[2]	76-87	76-87	63-74
Philpots Island	62	59	56	
Marine Grid 7	63-87	89	89	63-87
Marine Grid 13	41-61	41-61	63-87	89
Marine Grid 12	20-39	63-87	63-87	89
Cape Liverpool	56	57	55	
Bathurst Bay		119		
Pond Inlet	72	65	65	72
Marine Grid 18	63-87	89	63-87	41-61
Clyde	68	65	96	80
Marine Grid 19	63-87	41-61	63-87	63-87
Marine Grid 23	20-39	63-87	63-87	63-87

[1] Wind speed listed according to class; maximum unknown
[2] Converted from the Beaufort Scale

According to Maxwell et al. (1980), gale force winds (65 km/h or stronger and lasting for a period of at least 6 hours) occur, on average, less than once per season and are equally likely to be southeast or northwest. One gale should be expected in September and two or three in October with winds reaching more than 90 km/h occurring at least once.

Wave Regime

Although waves, when compared to winds and currents, are not a major driving influence for oil movement, they do increase the rate of oil loss through evaporation, produce emulsions and increase the difficulties in containment and removal of oil from the water surface (Fingas et al., 1979). Oil on the shoreline itself is also subject to wave-induced degradation processes and the rate at which these processes occur is directly related to levels of incoming wave energy (Owens, 1977). Due to a lack of wave data from this region there are no synoptic wave charts. Within the S.S.M.O. marine grids, shipboard observations indicate maximum wave heights ranging from about 4.5 m in Lancaster Sound to 9.5 m in Baffin Bay (Fig. 5). Because data derived from ships rarely include extreme weather conditions, these heights are probably minimal.

Marex (1972) used visual wave observations from Baffin Bay and Lancaster Sound during July to October, 1972, to generate wave prediction models. These suggest that significant wave heights increase from northern Baffin Bay southwards to the Baffin Island coast (Table 3).

Visual observations as well as direct measurements using wave gauges were conducted in Lancaster Sound during July, August and September 1976 by Oceanographic Services Limited (1977) for Norlands Petroleums Limited. Significant wave heights ranged from 0.9 to 1.8 m and during three storms the significant wave height was 3.1 m. Similar heights are predicted by Maxwell et al. (1980). For Lancaster Sound, they estimated significant wave heights of 2.9 m for a two-year return period and 6.4 m for a fifty-year return period.

For northwestern Baffin Bay, the greater range of potential fetches results in wave heights approximately 1.5 times greater than those obtained in Lancaster Sound (Maxwell et al., 1980). For a two-year return period the estimated significant wave height is 4.5 m and 9.3 m for a fifty-year return period. For the period 1953 to 1977, the maximum significant wave height indicated by Maxwell et al. was 8.8 m produced by a storm occurring in 1962.

There are no known wave observations in the Pond Inlet, Eclipse Sound and southern Navy Board Inlet waterway but with limited fetches and the enclosed nature of this area, the wave climate will have lower energy than Lancaster Sound and Baffin Bay. The maximum fetch is about 120 km along the east to west axis of Pond Inlet and Eclipse Sound and strong easterly or westerly winds in combination with ice-free conditions may generate high wave energy levels.

Currents and Tides

Offshore Currents

In general, the resultant movement of surface water throughout the Arctic Islands is from the Arctic Ocean to the southeast, through the inter-island channels and eastwards through Lancaster Sound (Dunbar, 1951; Bailey, 1957; Collin, 1962; Marex, 1972; and Fissel and Wilton, 1978). In northwest Baffin Bay, the cold Canadian current flows south, intruding into Lancaster Sound where it flows west along the north side of the Sound penetrating at least as far as Maxwell Bay (Canadian Hydrographic Service, 1970). This westerly flow is eventually checked by the eastward drift resulting in a reversal of direction and easterly transport along the south side of the sound (Fig. 6). Once out of Lancaster Sound, the easterly flow is deflected southwards down the east coast of Baffin Island by the Canadian current.

The eastward drift has been estimated as high as 90 km/day (194 cm/s) (Canadian Hydrographic Service, 1978a) and Fissel and Marko (1978) have used satellite-tracked buoys

Table 3. Summary of Open Water Wave Height Predictions (from Marex, 1972)

Area	Period	% of Waves less than 0.6 m (Hs)[1]	Wave height exceeded 50% of the time (Hs)	Wave height exceeded 10% of the time (Hs)	Maximum wave height likely during period (Hs)	Maximum wave heights likely to occur only once in 100 such periods (Hs)	(H_{max})[2]
Northern Baffin Bay	July to September	46%	0.7 m	2.1 m	5.8 m	9.4 m	18.3 m
Bylot Island area	August to mid-October	44%	0.7 m	2.4 m	6.7 m	11.0 m	21.6 m
Baffin Island northeast coast	August to mid-October	34%	0.9 m	2.9 m	7.3 m	12.2 m	23.8 m

[1] Hs: Significant wave height; the mean height of the highest third of all the waves present.
[2] H_{max}: Extreme wave height; approximately 1.8 times the significant wave height.

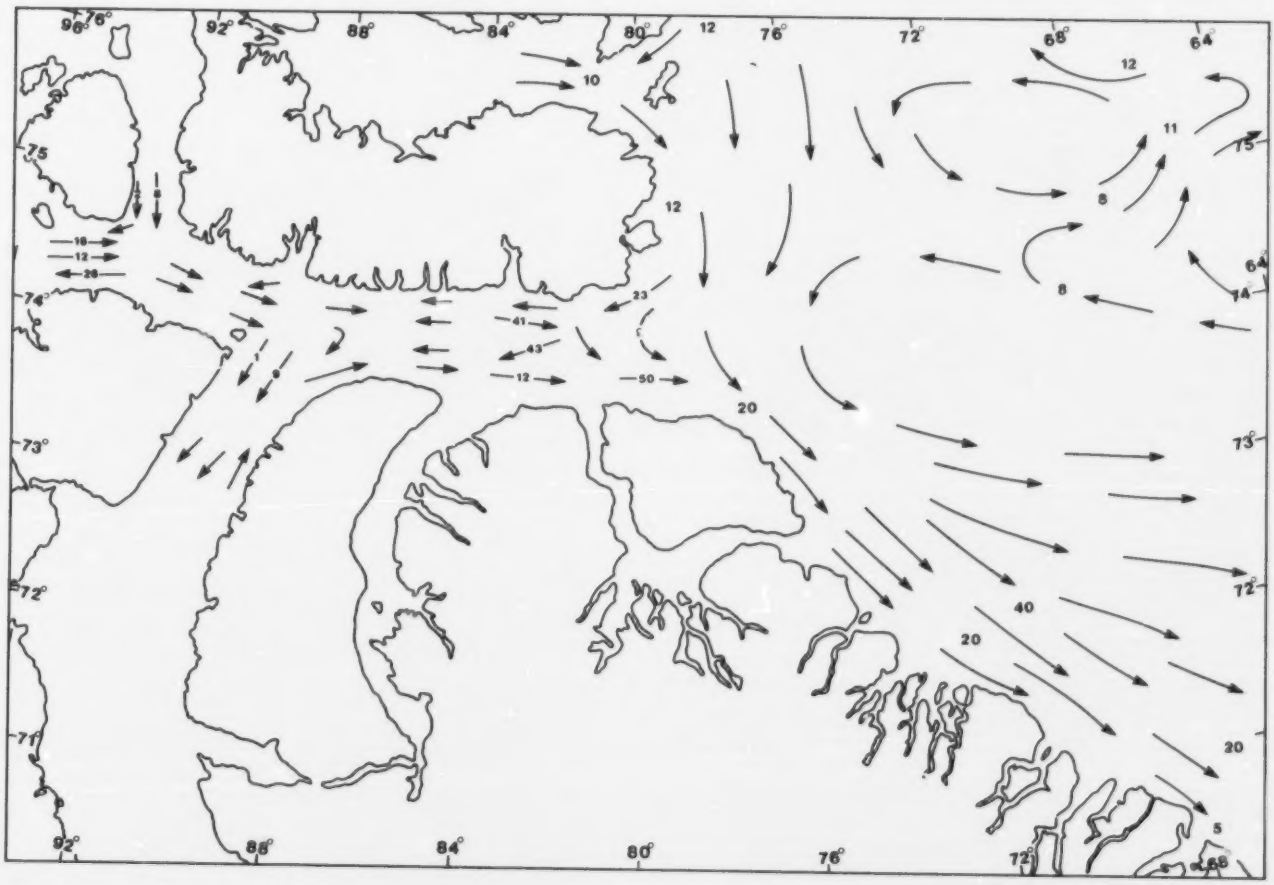

Figure 6. *The generalized surface circulation of Lancaster Sound from Collin (1962) in Fissel and Marko (1978). Values are in cm/s.*

Figure 7. *Steep rock cliff (SR) about 600 m high on the west side of Navy Board Inlet. PSC = 1. GSC 190726*

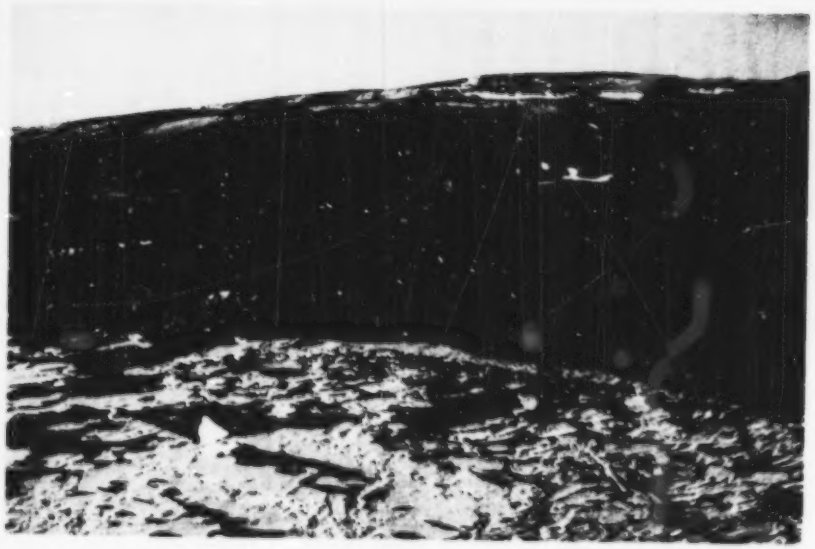

Figure 8. *Steep rock cliff (SR) about 30 m high on the north coast of Borden Peninsula. PSC = 1. GSC 190729*

Figure 9. *Moderate sloping rock coast mapped as mR-pBc; southeast coast of Devon Island. PSC = 3. GSC 190722*

Figure 10. *Low sloping unconsolidated coast at Cape Liverpool; north coast of Bylot Island. (1U:cBg) PSC = 4. GSC 190701*

to observe speeds along the south side of Lancaster Sound of 80 km/day (93 cm/s). The manner in which the east and west flowing waters mix and interact is not well understood (Lancaster Sound Environmental Assessment Panel, 1979). Complex eddy patterns have been noted by several authors, particularly at the confluence of channels entering the sound (Ramseier et al., 1975; Marko, 1977; Stepney, 1977; Markham, 1977). Fissel and Wilton (1978) have suggested that further surface and sub-surface current observations must be made to delineate such variations in circulatory pattern.

Tides

Few long-term or year-round tide data are available in the region. In general, the tidal wave progresses northwards from the Clyde area and west into Lancaster Sound (Dohler, 1966). The tides are a mixture of diurnal and semi-diurnal components having two complete oscillations daily with inequalities both in height and time. They range from less than one metre at Clyde Inlet, increase northwards and westwards into Pond Inlet and Lancaster Sound, to a maximum of 2.6 m and 2.9 m respectively (Appendices IIa, IIb and IIc).

Tidal Currents

The pattern, orientation and magnitude of tidal currents in Lancaster Sound and northwest Baffin Bay are as yet not well understood and until recent years data have been scarce. Tidal current information included in the Pilot of Arctic Canada and Sailing Directions, Arctic Canada (Appendix IIc) indicates that the tidal stream runs north-south at Clyde Inlet and west-east in Pond Inlet/Eclipse Sound with velocities of up to 101 cm/s.

From oceanographic studies conducted in 1960, Barber (1979) did not observe well-defined tidal movement in eastern Lancaster Sound but a cursory examination by Barber (1979) of currents 10 m below the surface farther to the west in 1974 indicated some tidal signal. A simple theoretical tidal model developed by Fenco (1974) for eastern Lancaster Sound predicated near maximum tidal current velocities of approximately 16 cm/s; however, the model is independent of depth and in shallow water may lead to erroneous results (Fenco, 1978).

A subsurface current meter installed by the Canadian Hydrographic Service near Cape Crauford at the tip of Brodeur Peninsula in 11 m of water recorded a mean current speed of 27.7 cm/s with a maximum speed of 90.4 cm/s (Fissel and Wilton, 1978). According to Milne and Smiley (1978) the tidal component of the currents measured near Cape Crauford was at times as high as 40 cm/s. Data from subsurface current meter moorings in eastern Lancaster Sound indicate that the diurnal and semi-diurnal tidal ellipses are found to be oriented along the east-west axis of the sound with typical speeds of 7 to 10 cm/s (Fissel and Wilton, 1978, p. 69). These current magnitudes from deep water moorings (i.e., greater than 700 m) are consistent with Fenco's (1974) predictions.

Summary

- Existing trajectory models indicate that the entrance to Navy Board Inlet and the north coast of Bylot Island is the most probable coastal region to be affected by an oil blow-out. However, no part of the remaining coast can be considered invulnerable.
- Oil can reach the shoreline only during the ice-free period which is probably less than 70 days in Lancaster Sound and western Baffin Bay (mid-July to the end of September) and less than 56 days in the Eclipse Sound – Pond Inlet region (end of July to the end of September).
- In Lancaster Sound, winds tend to be bi-directional in east and west directions. East winds are strongest whereas west winds occur somewhat more frequently, particularly in the latter half of the open water season. Winds of the longest duration, however, are generally from the north and northwest. An oil slick in Lancaster Sound will have little chance, therefore of being blown clear of the Sound before impinging on the shoreline.
- Within Navy Board Inlet, Eclipse Sound and Pond Inlet winds are controlled dominantly by topography resulting in directions parallel to the shoreline. South and southeast winds appear to be most frequent but the strongest winds are from the northeast and east. Oil reaching this region will have little chance to escape prior to shoreline contamination.
- In northwest Baffin Bay winds from the east and southeast are strongest and most frequent during July and August. North and northwest winds become more frequent in September and October suggesting that the northeast coast of Baffin Island may become increasingly vulnerable to oil contamination throughout the open water season.
- During the open water season, relative wave energies acting on the coast are moderate for Lancaster Sound and Eclipse Sound and high for the coasts exposed to Baffin Bay. Wave energy decreases rapidly inside the bays and fiords that dominate the east cost of Baffin Island. In storm conditions, significant wave heights can be greater than three metres and greater than eight metres in Lancaster Sound and Baffin Bay respectively.
- Regional currents will tend to drive oil westwards along the north side of Lancaster Sound, eastwards on the south side and southwards down the coast of Baffin Island. Although currents of 100 cm/s have been observed, the regional trend is frequently interrupted by complex and poorly understood circulatory patterns.

PHYSICAL SENSITIVITY

Rationale

The physical sensitivity of a shoreline as defined on page 2 is dependent on the fate and behaviour of oil which in turn relates to the complex interrelationships among the processes active on a coast and its sedimentologic-geomorphic characteristics (McLaren, 1981). The latter, therefore, provide the fundamental basis to assess the physical sensitivity. A scheme of coastal descriptions was developed to meet several requirements and under certain constraints, namely:

- each part of the descriptive system is informative with respect to the behaviour and/or cleanup of oil,
- coastal units are mappable from low level oblique airphotos with supplementary information from high level (9144 m) vertical photos and ground truth observations,
- the descriptive system gives an indication of the importance of the component parts,
- the system is adaptable to accommodate unforeseen environments encountered during the actual mapping,
- the final maps are readily understood.

Descriptive Legend

Coastal lengths determined by geomorphic similarity and within the limitations imposed by a map scale of 1:250 000 constitute "mappable units", the dominant characteristics of which are identified by a capital letter (Table 4). The first characteristic defines the nature of the unit and can be either G (glacial ice), R (rock coast)

or U (unconsolidated coast). This can be followed by B and I denoting the presence of a beach and an intertidal flat respectively. A lower case letter added as a prefix on the characteristic designates a geomorphic description and a lower case suffix provides a material classification. A system of symbols separating the characteristics indicates their relative abundance within the mappable unit (Table 4), enabling numerous permutations and combinations of coastal descriptions (see Appendix III). Deltas are mapped with an appropriate symbol as a specific coastal feature.

Slope

The overall slope of the coastal zone is mapped as steep (s), moderate (m) or low (l) (Table 4). Steep coasts are greater than 45° and usually denote cliffs (Fig. 7). No differentiation is made for the height of the cliff and "s" can apply equally to the 1000 m precipices flanking many of the fiords as well as to steep bluffs less than 30 m high (compare Figs. 7, 8). Moderate (m) slopes encompass the range between about 3° and 45° (Fig. 9), whereas low slopes (l) are essentially flat (Fig. 10).

Although the slope prefix applies only to the exposed land surface, the same slope is presumed to continue at least into the shore zone. Thus the physical sensitivity of the coast will increase as slope decreases (Table 4) because:

(i) mechanical energy available to abrade and disperse oil deposited on the shoreline is inversely related to slope. On steep or cliffed coasts, wave energy is dissipated in a relatively narrow zone at the base of the cliff. Waves are frequently transmitted seawards colliding with incoming waves resulting in turbulent conditions and inhibiting deposition of oil. On moderate and low sloping coasts, wave energy becomes progressively dissipated over increasingly larger distances.

(ii) as slope decreases, the width of the intertidal zone increases exposing larger areas for potential oil contamination.

Glacial (G), Rock (R) and Unconsolidated (U) Coasts

Like slope, these three descriptors characterize the overall nature of the coastal zone. Glacial shorelines (G) (Fig. 11) are considered to be less sensitive than either rock (R) or unconsolidated (U) coasts because:

(i) diving observations indicate that there are neither fauna nor flora associated with the sub-marine glacial ice, and

(ii) oil is unlikely to adhere to glacial ice.

Unconsolidated coasts, however, are more sensitive than the other two coastal types (Table 4) because of the greater likelihood of long term containment of oil in sediments, either by burial or penetration.

Beach (B)

In this report, the term "beach" is used in a restricted sense to include only the deposits of the backshore (overwash deposits and berm) and beach face (Fig. 12). Its presence on either a rock or unconsolidated coast increases the physical sensitivity of the shoreline because:

(i) a beach acts as a reservoir for oil that has penetrated into the sediment,

(ii) littoral processes acting on a beach can bury stranded oil resulting in slow release of hydrocarbons across the intertidal zone (Owens, 1977).

Table 4. Descriptive legend for the coasts of eastern Lancaster Sound, northwest Baffin Bay

Prefix		Characteristic	Suffix
N/A		G - glacier	N/A
s - steep (cliff) slope m - moderate slope l - low slope	Increasing Physical Sensitivity ↓	R - coast is contructed in bedrock	N/A
s - steep (cliff) slope m - moderate slope l - low slope		U - coast is constructed in unconsolidated materials	N/A
p - pocket c - continuous b - barrier		B - beach	b - boulder s - sand g - gravel c - cobble
n - narrow w - wide		I - intertidal flat	b - boulder s - sand g - gravel c - cobble

Note: Three symbols separate the characteristics
i. / <20%
ii. - 20% to 80%
iii. : >80%

e.g. mR-bBg/nIs. The mappable unit is a moderately sloping, rock coast; 20% to 80% of its length is composed of gravel barrier beaches and less than 20% contains a narrow intertidal zone composed of sand.

(iii) stranded oil can weather on the beach surface and form an asphalt which may in turn disrupt normal beach processes, and

(iv) cleanup procedures for beaches can also disrupt normal beach processes and result in shoreline erosion.

The type of beach is designated by a prefix (p = pocket, c = continuous, b = barrier) (Table 4). Pocket beaches (Fig. 9, 13) are considered least sensitive among the three kinds of beaches because:

(i) the relatively small amount of beach material results in the smallest reservoir potential for oil storage,

(ii) their location between rocky headlands provides means for both simple protection and facilitates cleanup measures.

Continuous beaches (Fig. 14) are characterized by the uninterrupted longshore transport of sediment. They are more sensitive than pocket beaches because:

(i) they have a greater reservoir potential for oil storage,

(ii) their exposure is greater resulting in increased difficulties for shoreline protection.

Barrier beaches (Fig. 15) either wholly enclose or partially enclose a tidal lagoon effectively tripling the amount of shoreline available for contamination. For this reason, barrier beaches are the most physically sensitive of the beach types.

The material of the beach is denoted by a suitable suffix (b = boulder, s = sand, g = gravel, c = cobble). The order of increasing sensitivity is determined by the relationship between the depth of oil penetration and sediment size. Oil tends to penetrate coarser sediments more easily than fine sediments (Long et al., 1981). Thus gravel and cobble beaches are more difficult to clean than sand beaches. Boulders are treated as an exception since cleanup techniques, although more limited, are possibly easier to employ than those for other materials. Boulder beaches are therefore considered to be the least physically sensitive of the beach materials.

Intertidal Flat (I)

This term is restricted here to intertidal flats composed of sedimentary deposits formed by present processes. It does not include the intertidal characteristics of coasts where there is no tidal flat. In the latter case, the width of the intertidal zone can be inferred directly from the slope prefix.

The presence of an intertidal flat increases the physical sensitivity of the shoreline because:

(i) a large area is exposed to potential contamination,

(ii) there are few effective cleanup methods available for intertidal flats (Owens, 1977),

(iii) intertidal flats, are found where wave energy is low, hence self-cleaning will be slow,

(iv) if oil penetrates into intertidal deposits or becomes buried, the rate of degradation will be very slow and may cease altogether if there are anaerobic conditions.

Intertidal flats are described as either narrow (n; <100 m) or wide (w; >100 m) (Fig. 16, 17) with a respective increase in physical sensitivity. The sedimentary material denoted by a code prefix (Table 4) follows the same physical sensitivity hierarchy used for beaches.

Physical Sensitivity Legend

The large number of combinations possible in the coastal descriptive system (Table 4) precludes a rapid assessment of relative physical sensitivity among the large number of mappable units (see Appendix III). However, each of the elements in the coastal description legend can be ranked in order of increasing physical sensitivity (Table 5). The values assigned to each of the coastal description elements are derived empirically and are based on the following assumptions:

(i) Glacial coasts (G) are the least sensitive of all other coastal types and receive a value of zero (Table 5),

(ii) All rock coasts (R) are less physically sensitive than unconsolidated coasts (U). Steep coasts are less sensitive than low sloping coasts. The values of 1 to 6 reflect this incremental increase in sensitivity from a steep rock coast (sR) to a low unconsolidated coast (lU).

(iii) The presence of beaches and intertidal flats increases the sensitivity of the shoreline. The relative abundance of both these features are mapped as <20% (/), 20% to 80% (-) and >80% (:). The midpoints of each of these ranges are 10%, 50% and 90% respectively. Therefore, the values assigned to reflect 20% to 80% and >80% are 5 times and 9 times greater than the value assigned to <20%. For example, /cB receives a value of 2 (Table 5); thus -cB and :cB must receive values of 10 and 18 respectively.

(iv) A barrier beach (bB) is subjectively considered to be twice as physically sensitive as a continuous beach (cB) which in turn is twice as physically sensitive as a pocket beach (pB). Similarly, a wide intertidal flat (wI) receives a value which is 2 times greater than the value for a narrow intertidal flat (nI).

(v) Beach and intertidal materials are largely based on airphoto interpretation. Inasmuch as the material classification has the greatest probability of error, the assigned values, although reflecting relative physical sensitivity, are kept low to avoid gross changes in the weighting of the physical sensitivity scale.

Table 5. Values applied to descriptive legend (Table 4) to obtain physical senstitivity ranking

	G = 0	
sR = 1		sU = 4
mR = 2		mU = 5
lR = 3		lU = 6
	/pB = 1	
	/cB = 2	
	/bB = 4	
	-pB = 5	
	-cB = 10	
	-bB = 20	
	:pB = 9	b = 1
	:cB = 18	s = 2
	:bB = 36	g = 3
		c = 4
	/nI = 8	
	/wI = 16	
	-nI = 40	
	-wI = 80	
	:nI = 72	
	:wI = 144	

Values are additive: e.g.,
lR-cBs/wIg = 3 + 10 + 2 + 16 + 3 = 34

Figure 11. *Glacial coast (G) on the west coast of Devon Island. PSC = 0. GSC 190702*

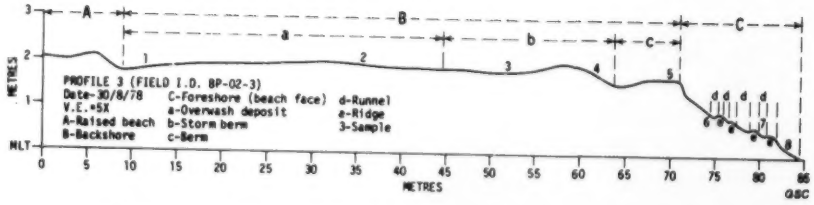

Figure 12. *Beach profile from the south coast of Devon Island showing typical morphological components.*

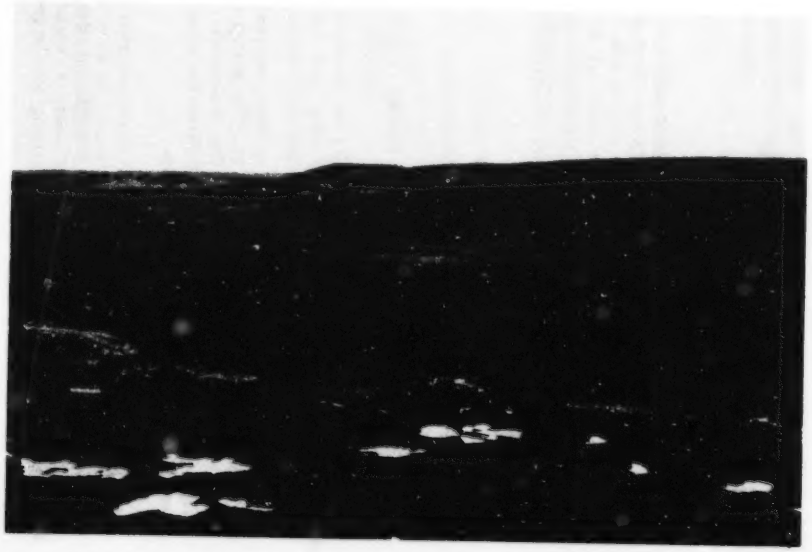

Figure 13. *Pocket beaches on the southeast coast of Eclipse Sound (mR-pBG-I) PSC = 6. GSC 190775*

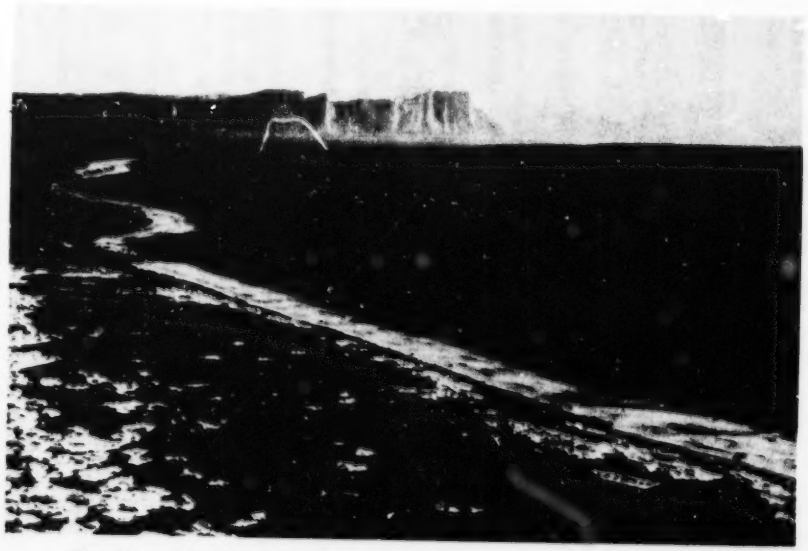

Figure 14. *Low sloping unconsolidated coast with continuous sand beaches at the entrance to Scott Inlet, west coast of Baffin Island. (1U:cBs) PSC = 4. GSC 190719*

These values when added together provide a large range: G = 0 to the most physically sensitive coast possible: a low sloping unconsolidated coastline containing greater than 80% of both cobble barrier beaches and wide cobble intertidal flats (1U:bBc:wIc = 194). Even with such a large range, four or five different combinations of coastal description frequently sum to the same value (see Appendix III). When this occurred no attempt was made to rank further the physical sensitivity of the environments within a single value.

Because a range of 1 to 194 is clearly unmanageable, this scale was further subdivided into 11 (0 to 10 inclusive) physical sensitivity categories (PSC) (Table 6). The categories were determined partly by subjective examination of the coastal descriptions and partly by natural breaks in the per cent frequency distribution of every combination of coastal description on the 1 to 194 scale (Appendix IV). The dominant characteristics and the abundance of each of the 11 physical sensitivity categories are listed in Table 6.

COASTAL ENVIRONMENTS AND OIL SPILLS

Glacial Coasts (G)

Distribution

Glacial coasts make up a total of 80 km (2%) of the shoreline (Table 7), the longest stretches occurring on Devon Island where outlet glaciers from the Devon Ice Cap reach Lancaster Sound. In the vicinity of Bethune Inlet, an ice front extends for 19 km along the shoreline (Fig. 11); elsewhere smaller valley glaciers are found scattered throughout the region with coastline lengths of 1.5 ± 1.2 km (Fig. 18). Glacial coasts are confined exclusively to the lowest physical sensitivity category (PSC) of zero (Table 6).

Impact and Persistence of Oil

Most of the glaciers discharging into coastal waters are retreating and are composed of calving ice cliffs. The area available for contamination is therefore small even if oil were able to adhere to glacial ice which is unlikely. Diving observations on glacier margins showed little fauna or flora associated with these glaciomarine environments. Oil impinging on glacial coasts is expected to have negligible impact.

Rock Coasts (R)

Distribution

Steeply sloping rock coasts (sR) make up 2663 km (54 per cent of the total coast); a further 3 per cent have some beach deposits associated with them (Appendix III). Generally, short segments of rock cliffs occur throughout the coasts of northeast Lancaster Sound, Navy Board Inlet and Milne Inlet. On the east coast of Baffin Island they are confined principally to the fiords where they are essentially ubiquitous; however, they do occur on the outer coast where they form small cliffed headlands. Cliffed coasts are found entirely in PSC 1 and are absent beyond PSC 4 with the exception of a small amount in PSC 7 (Table 8).

Moderate sloping rock coasts (mR) encompass 710 km of shoreline (14 per cent) of which nearly half contain varying amounts of beach or intertidal deposits. They are found principally on the outer coasts and the seaward margins of fiords. The largest amount of moderate sloping rocks coasts is contained in PSC 2, but they occur more or less randomly throughout the categories from PSC 2 to PSC 9 (Table 8).

Low sloping rock coasts are virtually absent (54 km or 1 per cent of the total coastline) and are confined almost entirely to southeast Devon Island where they are associated with barrier beaches and wide intertidal flats.

Impact and Persistence of Oil

On steep rock coasts the width of the intertidal zone is small and wave energy is expended directly onto the rock face. If waves are reflected, oil can be prevented from being stranded altogether. The splashing of breaking waves can throw oil far above normal high tide level and oil will tend to seep down over the rock in thin layers. With decreasing slope, the thickness of oil layers can increase as can the width of the intertidal zone available for contamination. Irregularities in the rock formed by weathering and fracture patterns can result in oil being trapped during this downslope movement which may be released again during the next floodtide. Oil that is already viscous from weathering prior to arriving at the shoreline is much more likely to remain as a coating on the rocks during subsequent tide cycles.

Within the shelter of the fiords where steep rock coasts are most common, the width of potential shoreline contamination is small and it is unlikely that oil will be thrown very far above the level of high water. Little is known of the persistence time of oil in arctic environments because of the complexities of ice-shoreline interaction and low temperatures. However, the relative longevity of oil on rock coasts in the order of increasing persistence time can be summarized as follows:

i Intertidal zone - exposed coast
ii Intertidal zone - sheltered coast
iii Supratidal zone - exposed coast
iv Supratidal zone - sheltered coast

Unconsolidated Coasts (U)

Unconsolidated coasts make up a total of 1248 km (26 per cent of the total coastline) of which 256 km are mapped as steep. The latter is commonly found on exposed coasts between fiords in association with continuous gravel or cobble beaches. Moderate sloping unconsolidated coasts are more common (646 km or 13% of the total coastline) and are generally located in more sheltered environments such as Milne Inlet and Eclipse Sound. The remaining 324 km (8 per cent) of unconsolidated coasts are low sloping and occur at deltas, outwash plains and low emerged coastal plains in Croker Bay and along the north coast of Bylot Island. Unconsolidated coasts are more physically sensitive than rock coasts because of their associated beaches and intertidal deposits. This shore type is absent from the first three categories of physical sensitivity and ranges from 28 km or 18 per cent of category 3 to 122 km (98%) of category 9 (Tables 7 and 8).

Beaches (B)

Distribution

Pocket beach (pB)

A very small amount of coast (3%) contains mappable amounts of pocket beaches (Table 7). They are confined to the southeast coast of Devon Island and on the eastern side of Eclipse Island on Baffin Island. They occur in variable amounts from PSC 2 to PSC 8 (Table 8).

Continuous beach (cB)

About 1300 km (27% of the total coast) contains continuous beach, of which 1061 km (22%) have concentrations of >80% (Table 7). Excluding fiords where beaches are absent, continuous beaches are the most ubiquitous sedimentological feature occurring on nearly all of the shorelines of Lancaster and Eclipse Sounds and the outer coasts of Bylot and Baffin Islands. They are present in PSC 3 to PSC 10 in varying amounts and are most abundant in PSC 4 where they make up 95% of the category (Table 8).

Figure 16. *Narrow intertidal flats formed on a rocky shoreline containing pocket beaches. Photo taken in Milne Inlet. (mR-pBg-nig) PSC = 6. GSC 190714*

Figure 18. *Valley glaciers discharging into Buchan Gulf, northwest Baffin Island (G) PSC = 0. GSC 190711*

Figure 15. *Barrier beach on the north coast of Bylot Island. (1U:bBg) PSC = 5. GSC 190708*

Figure 17. *Wide intertidal flats on the west coast of Navy Board Inlet. (1U:wls) PSC = 10. GSC 190712*

Table 6. Physical sensitivity legend

Physical sensitivity category (PSC) in order of increasing sensitivity	Coastline length (km)	Per cent of total coast	Dominant characteristics (see Table 8 and Appendix III)
0	80	2	Glacier coastline; most common on Devon Island or as isolated valley glaciers on the sides of fiords (Fig. 11, 18).
1	2663	54	Steep sloping rock coasts; no beaches or intertidal flat deposits. Very common throughout study area and in nearly all fiords (Fig. 7, 8).
2	490	10	Predominantely moderate sloping, rocky shoreline with no beaches or intertidal deposits. Occasionally contains less than 20% pocket beaches. Common on fiord sides or on exposed outer headlands.
3	153	3	Moderate sloping rock coast and steep sloping unconsolidated coast with 20% and 80% continuous beaches. Found on the southeast coast of Devon Island and the exposed shores of Eclipse Sound (Fig. 9).
4	1003	20	Mostly unconsolidated coast with greater than 80% continuous beach. Common on the outer exposed coasts of Baffin and Bylot Islands (Fig. 10, 14).
5	63	1	Moderate and low sloping unconsolidated coast with greater than 80% barrier beaches. Found on the north shore of Bylot Island (Fig. 15).
6	127	3	Moderate sloping rock and unconsolidated coast with greater than 80% continuous beach and between 20% and 80% narrow intertidal flat deposits. Present on the east side of Eclipse Sound, Milne Inlet and several contiguous fiords (Fig. 13, 16).
7	85	2	Moderate sloping rock coast with few beaches and greater than 80% narrow intertidal flats. Found on some of thc fiord sides in southern Eclipse Sound.
8	13	1	Moderate and low sloping rock or unconsolidated coast with 20% to 80% continuous beaches and greater than 80% narrow intertidal flats. Found only in Milne Inlet and Tremblay Sound in the southwest region of Eclipse Sound.
9	124	3	Mostly moderate and low sloping unconsolidated coasts with 20% to 80% continuous beach and greater than 80% narrow intertidal flats. Found mostly on the west coast of Navy Board Inlet and Milne Inlet.
10	116	2	Mostly low sloping unconsolidated coast with either continuous or barrier beach and greater than 80% wide intertidal flats. Found in Koluktoo Bay and both sides of Navy Board Inlet (Fig. 17).

Table 7. Coastline lengths (km) of the descriptive elements (Table 4) within the physical sensitivity categories (PSC) (Data derived from Appendix III)

	Glacial Coasts	Slope			Rock Coasts				Unconsolidated Coasts				Beaches									Intertidal Flats						
PSC	G	s	m	l	R	sR	mR	lR	U	sU	mU	lU	B	/pB	-pB	:pB	/cB	-cB	:cB	/bB	-bB	:bB	I	/nI	-nI	:nI	/wI	-wI	:wI
0	80																												
1		2663			2663	2663																							
2		85	401	4	484	79	401	4	6	6				29															
3		37	107	9	125	17	98	9	28	20	8		153		49		18	87											
4		289	523	191	163	61	81	22	840	229	442	169	1003						948		55								
5			22	41	12		7	4	51		15	36	63									63							
6			124	3	56		53	3	71		70	1	127	3	33			14	76				127		127				
7		4	60	21	69	4	60	5	16			16	11	5			6						85			85			
8			8	5	8		8		5			5	13		3			10					13			13			
9		2	91	31	2		2		122	2	89	31	124					133				11	124			120		4	
10		3	22	90	7			7	109	3	22	84	73						37			36	116						116
TOTAL	80	3083	1358	335	3589	2824	710	54	1248	260	646	342	1568	37	85		24	224	1061		55	110	465		127	218		4	116
% of Total Coastline	2	63	28	8	73	57	14	1	26	5	13	8	32	1	2		0	5	22		1	2	9		3	4		0	2

Table 8. Per cent of each of the descriptive elements within the physical sensitivity categories (PSC)

	Glacial Coasts	Slope			Rock Coasts				Unconsolidated Coasts				Beaches									Intertidal Flats						
PSC	G	s	m	l	R	sR	mR	lR	U	sU	mU	lU	B	/pB	-pB	:pB	/cB	-cB	:cB	/bB	-bB	:bB	I	/nI	-nI	:nI	/wI	-wI	:wI
0	100																												
1		100			100	100																							
2		17	82	1	99	16	82	1	1	1				6															
3		24	70	6	82	11	64	6	18	13	5		100		32		12	57											
4		29	52	19	16	6	8	2	84	23	44	17	100						95		5								
5			35	65	19		11	7	81		24	57	100									100							
6			98	2	44		42	2	56		55	1	100	2	26			11	60				100		100				
7		5	71	25	81	5	71	6	19			19	13	6			7						100			100			
8			62	38	62		62		38			38	100		23			77								100			
9		2	73	25	2		2		98	2	72	25	100					91				9	100			97		3	
10		3	19	78	6			6	94	3	19	72	63						32			31	100						100

Barrier beach (bB)

Concentrations of <20% barrier beach (/bB) do not occur; greater concentrations, 20% to 80% (-bB) and >80% (:bB) form only 1% and 2% of the coastline respectively. Small streatches of barrier beaches are found on the southeast coast of Devon Island, otherwise they are almost exclusively confined to northeast Bylot Island. They are the dominant sedimentological feature of PSC 5 although minor occurrences are found in PSC 9 and PSC 10 (Table 8).

Morphology and Sedimentology

Pocket Beach

The limited number of pocket beaches occurring in the Lancaster Sound region are almost exclusively confined to moderate sloping rock coasts where they form in small sheltered niches between headlands (Fig. 9). They are generally less than 300 m long and are composed principally of coarse rather than fine sediments. Of the 122 km of mappable units containing pocket beaches, 35% are gravel, 29% boulders, 19% cobbles and the remaining 18% are sand (Appendix III). Because of their association with coasts where sediment is scarce, the beaches are generally narrow, and the backshore usually less than 10 m wide or absent altogether (Fig. 19). The width and slope of the beach face, however, do not differ significantly from those measured on either the continuous or barrier beaches.

Continuous beach (cB)

Of 1309 km (27% of the whole coastline) containing mappable quantities of continuous beach, 613 km (13%) are gravel followed by 276 km (6%), 282 km (5%) and 119 km (3%) composed of cobbles, sand and boulders respectively (data from Appendix III). About 1000 km (20% of the whole coast) are formed on unconsolidated coast. Analyses of beach profiles from each of the study sites (Fig. 1) and representative sediment samples (McLaren et al., 1981) indicate the following:

(i) The average width of back beach that is subject to oil contamination is 29 ± 16 m (Fig. 20).

(ii) The average beach face width subject to possible oil contamination is 20 ± 8 m.

(iii) Beach face slopes range from 22° on boulder beaches to less than 6° on sand. The average slope is 9 ±5°. Unlike beaches in more temperate environments, there are very poor relationships among beach face slope, per cent gravel and mean grain size. This is probably due to the effects of ice processes modifying the beach face.

(iv) The amount of gravel-sized clasts and larger ranges from less than 5% on sand beaches to 100% on boulder beaches. Boulder sizes are typically -8ϕ to -10ϕ (Fig. 21). Excluding the gravel content which averages about 53 to 37 per cent, the mean grain size of sand sizes and smaller is 0.75 ± 0.47ϕ (coarse sand) and the sorting is 0.81 ± 0.20ϕ. On beaches mapped as sand, the finest mean grain size is medium sand (1.50ϕ) and mud is virtually absent (McLaren et al., 1981).

Barrier Beach

In the 165 km of coast containing barrier beaches, the greatest proportion is composed of gravel (64 km; 1.3% of the total coast) followed by sand (46 km; 0.9%), boulders (32 km; 0.7%) and cobbles (22 km; 0.4%). With the exception of the presence of a lagoon, their morphology does not differ significantly from those of continuous beaches (Fig. 22).

Impact and persistence of oil

The behaviour of oil impinging on a beach is subject to numerous parameters such as the state of weathering and viscosity of the oil, the nature of the beach sediments, the stage of the beach cycle and ambient temperature. Discussion of the interaction of oil with beaches may be found in Owens, (1977) and McLaren, (1980). For arctic environments such discussions are of limited value because of the overriding presence of ice, which in itself has a complex interaction with beach sedimentation and processes.

At the height of the open water season, the behaviour of oil on arctic beaches may be similar to that on temperate beaches. In recent oil spill experiments at Cape Hatt in Eclipse Sound, natural cleaning rates for the exposed and semi-exposed beaches were higher than expected. Some gravel and cobble beaches exposed to the full 90 km fetch of Eclipse Sound became completely free of oil after only 12 weeks during an open water period. Even on relatively sheltered beaches, summer runoff from the land and a melting frost table combined to produce sufficiently high water tables to inhibit oil from being stranded on the beach (Owens et al., in press). On the other hand, low air and water temperatures will tend to increase the oil's viscosity, thus increasing the clinging properties of the oil to the sediment. Once stranded on the beach, oil will locally decrease the surface albedo and the resulting increase in ground temperature may affect the normal growth and decay of the frost table. Such perturbations may affect normal beach processes by increasing the ease of erosion in sediments that are usually frozen.

During and after breakup, drifting ice pans can be blown onto the beach face producing a number of features unique to polar beaches. These include ice push ridges (McLaren, 1982 and Fig. 23), ice mounds, (Owens and McCann, 1970) and pitted beaches (Nichols, 1961 and Figs. 20, 24). Ice push can modify considerably beach morphology, a process which may be helpful in breaking apart pavements and enabling oil to degrade more rapidly. The same process however, will also mix and bury oil deeper into the sediments inhibiting cleanup operations. During storms, ice blocks are thrown onto the berm and beach face forming ice pits as they melt. Such pits may form natural traps for oil resulting in both a larger amount of potential contamination and increased cleanup difficulties.

With the approach of winter, freezeup begins when sea temperatures approach -2.2°C and spray from waves begins to freeze on the beach. Initially a slush-foot (Taylor, 1973) is formed followed by a substantial ice foot as air temperatures decrease. The ice foot is defined as the ice formation which joins the land and sea between high and low water marks (Joyce, 1950). At least seven kinds have been described (Wright and Priestly, 1922) and McCann and Carlisle (1972) have a good discussion and review in detail the literature on the subject. There is, however, considerable controversy on both ice foot formation and the effects it has on the beach. Early workers such as Joyce (1950) considered the ice foot as an important agent of erosion because when it breaks up it rafts away large quantities of beach material on its undersurface. Such a process may result in considerable cleaning of an already contaminated beach.

Other workers (Rex, 1964; Moore, 1966) have suggested that an ice foot plays an active role in beach sedimentation. During its growth, sediments are incorporated into the ice resulting in a finely bedded, ice-cemented conglomerate which mantles the beach. It thaws in place without breaking away from shore allowing sand and gravel to be added to the beach surface. Oil that is already on the beach or oil that is incorporated into the ice foot during its growth may undergo considerable mixing with the sediment during the

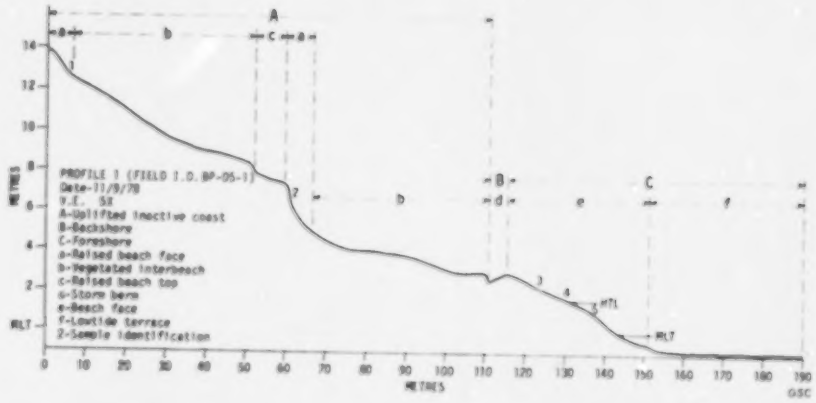

Figure 19. *Profile from a pocket beach on the east side of Eclipse Sound.*

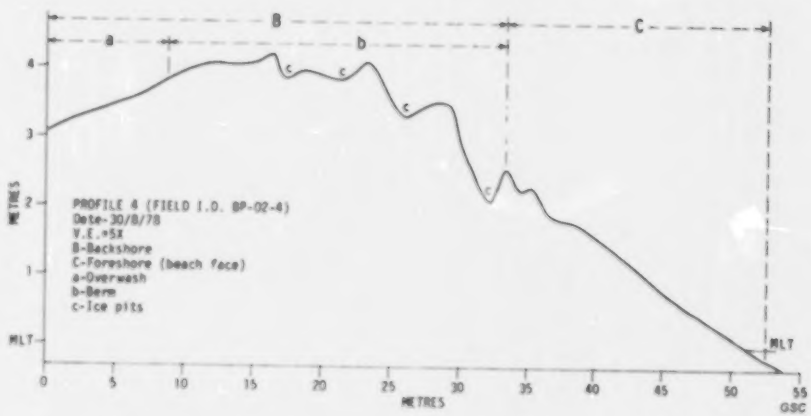

Figure 20. *Profile from a continuous gravel beach on the south coast of Devon Island.*

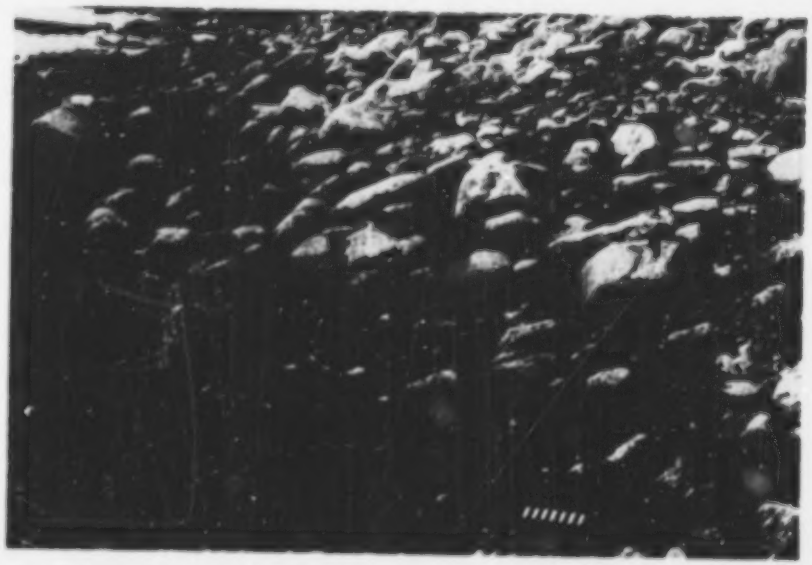

Figure 21. *Boulder Beach on the south coast of Philpots Island (eastern Devon Island). Scale is 15 cm. GSC 1907 17*

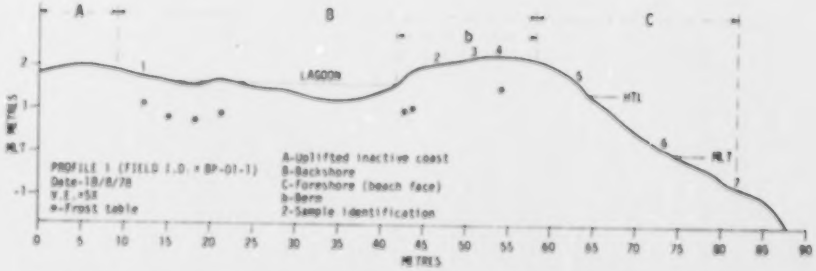

Figure 22. *Profile of a barrier beach on the south coast of Philpots Island, eastern Devon Island.*

following melt. Again, a decreased albedo caused by the oil may result in a more rapid melting of the ice foot disrupting the normal sequence of beach processes.

The various kinds of ice foot are determined by a combination of (i) wave activity during freezeup, (ii) the amount of ice present on the beach at freezeup, (iii) tidal range and, (iv) beach slope. The exact effects of oil on its formation and decay are presently unknown; however, it seems clear that the net result of an ice foot would be to remove oil from the beach during the melt or to "dilute" the oil-in-sediment concentration through excessive disturbance and admixing of sediments.

Regardless of exposure, the effects of ice interacting with the beach will disturb "normal" oil-sediment behaviour. Unlike beaches in temperate climates, there may not be the same direct correlation between coastal exposure and persistence time of oil. For example, the coastal morphology and sedimentology of Labrador reflect relative exposure to wave processes which, in turn, provide the rationale for the physical sensitivity of the shoreline (McLaren, 1980). In arctic environments, this relationship is less clear particularly in physical sensitivity categories below 8 (PSC 9 and 10 do tend to be in the sheltered, least exposed environments). This is due to the ubiquitous effects of ice which, as a process, is more important than waves and is less dependent on the fetch/exposure conditions.

Because of ice effects, it is possible that within a single year, sediment disturbance will have dispersed oil concentrations on the beach face to make cleanup impractical, impossible or even unnecessary. On boulder beaches such as on the south coast of Philpots Island (Fig. 21) ice could be expected to have less effect, thus residence time of oil might be greater than that on finer beach materials. However, in this case, the boulder beaches are found on a very exposed coastline and natural cleaning by wave processes may counterbalance the smaller effects of ice.

If contamination of beaches occurs during periods of high wave activity, oil may be thrown beyond the beach face to the backshore where it could become incorporated into berm and overwash deposits. Out of reach of ice processes, the persistence time of oil could be very long, perhaps many years if burial occurs.

Table 9. Summary of intertidal flat deposits (data derived from Appendix III)

	nl		wl	
	km	%	km	%
IR	8	2	7	5
mR	123	36	0	0
sR	4	1	0	0
IU	48	14	87	73
mU	159	46	22	18
sU	2	1	3	3
Total	345	100	120	99
s (sand)	90	26	98	85
g (gravel)	15	5	7	6
c (cobbles)	9	3	5	4
b (boulders)	8	2	0	0
No qualifier	223	65	7	6

Intertidal Flats (I)

Distribution

Intertidal flats make up only 9 per cent of the total shoreline (Table 7) and occur predominantly on either side of the south end of Navy Board Inlet and inside Milne Inlet. Small amounts are also present in Bethune Inlet on the west side of Philpots Island and on the southwest shore of Croker Bay. They are essentially absent on the east coast of Baffin Island and the northeast coast of Bylot Island.

Concentrations of <20% intertidal flat do not occur and they are absent altogether in physical sensitivity categories 0 to 5. From PSC 6 to 10 however, they are found in 100 per cent of all the mappable units with concentrations of >80% narrow intertidal flats predominating in PSC 7 to 9 (Table 8). PSC 10 is entirely made up of >80% wide intertidal flats.

Morphology and Sedimentology

No specific grain size or morphological data were acquired for intertidal flats; however an analysis of Appendix III indicates the following (Table 9):

(i) Narrow intertidal flats occur predominantly on moderately sloping coasts (82% of the 345 km of shoreline containing narrow intertidal flat deposits). They are only slightly more common on unconsolidated rather than rock coasts.

(ii) Nearly all wide intertidal flats are associated with unconsolidated coasts of which the largest number are formed on low slopes.

(iii) Sand is the most common substrate found on both narrow and wide intertidal flats, although for the majority of narrow intertidal flats airphoto interpretation did not allow a reliable identification of the material.

Impact and Persistence of Oil

An intertidal flat provides the greatest area of coastal sediments available to oil contamination. Found typically in sheltered regions the physical sensitivity of analagous environments in temperate latitudes is very high (Gundlach et al., 1981). In general, oil is deposited over the intertidal flat during an ebb tide and, depending on its viscosity, can either penetrate or cling to the sediments. Low wave energies allow the oil to persist in such environments for five to ten years and possibly more.

In arctic environments, however, it is probable that, due to the effects of nearshore ice, intertidal flats do not increase so dramatically the physical sensitivity of coastlines. During freezeup, contaminated sediments may freeze onto the underside of intertidal ice which, at breakup may be transported and dispersed into the offshore or other nearshore environments. During breakup and throughout much of the open water season intertidal flats are subject to considerable reworking by drifting ice, the effects of which will be to abrade and mechanically disperse oiled sediments.

Although it is still reasonable to place intertidal flats in the high physical sensitivity categories because of an increase in the area of coastal contamination, high potential for oil storage and cleanup difficulties, it must be emphasized that the effects of ice are largely unknown. Almost certainly ice will decrease the longevity of oil in these and other environments; thus the significance of the physical snesitivity scale may be less than previous scales such as devised by Michel et al. (1978) and McLaren (1980).

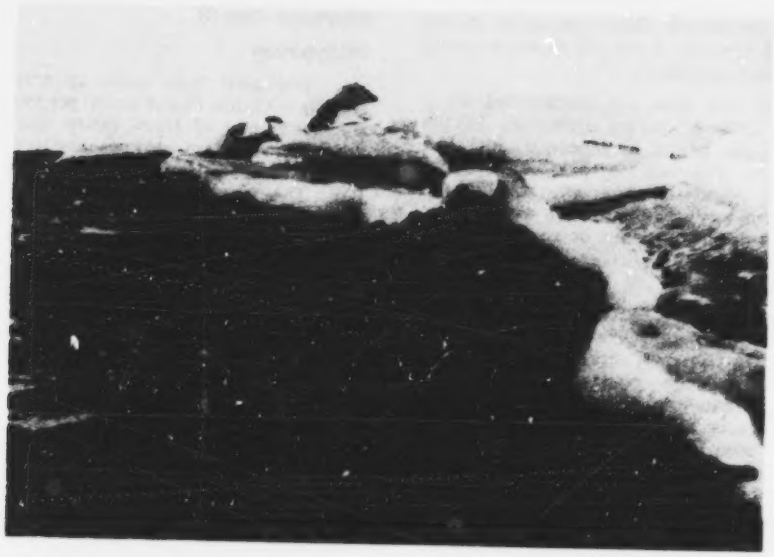

Figure 23. *Example of ice push ridges formed by drifting pack ice blown onto the beach. GSC 190705*

Figure 24. *Ice pits in beaches on the north coast of Bylot Island. GSC 190725*

SHORELINE PR)TECTION AND CLEANUP

Less than 6 per cent of the coastline falls in high physical sensitivity categories (PSC 8, 9, 10; Table 6) suggesting that for purely physical reasons protection and cleanup will not be a very high priority. Furthermore, the small population in such a remote area, extremely expensive logistics with respect to transport of people and equipment, and the difficulties of operating effective countermeasures in an ice environment combine to make protection and cleanup unrealistic for anything more than small local priorities. Clearly areas of biological concern will have precedence.

The decisions to protect or not to protect, to cleanup or to leave alone, will be based on a large number of variables of which the physical sensitivity is one. Robilliard et al. (1980) provided a practical guide to making rapid, correct decisions taking into account both biological and physical data. There are no countermeasure or cleanup techniques that are unique to arctic environments and their use will require summer, ice free conditions. These methods are discussed in Robilliard et al. (1980), McLaren, (1980) and Owens (1977).

SUMMARY

1. This report contains two sets of coastal maps of eastern Lancaster Sound and northeast Baffin Island. The first shows geomorphology and sedimentology of the shoreline; the second, derived from the first, presents the coast in terms of 11 physical sensitivity categories. As the categories increase from 0 to 10, so do the persistence times of oil in the environment, cleanup difficulties and potential damage to the environment by cleanup operations. The physical sensitivity maps provide a rapid assessment of the coastal environments that warrant protection, whereas the descriptive maps will provide the basis for selecting appropriate cleanup procedures should oil pollute the coast.
2. Oil can first encroach onto the shoreline only during the ice free period and after the ice foot has disappeared. Ice free periods typically are less than 70 days (mid-July to the end of September) in Lancaster Sound and western Baffin Bay. In the Eclipse Sound – Pond Inlet region ice free days extend from the end of July to the end of September (about 56 days).
3. The effects of ice on the beach and in the shore zone encompass a variety of processes. Throughout most of the year ice will protect the shore from contamination. At breakup, thawing of the ice foot will tend either to rework or remove beach sediment. During the open water season all coastal environments are subject to the effects of mobile ice reworking both nearshore and beach sediments. Such processes may result in burying stranded oil potentially increasing its longevity; however, more probably the effects of ice will significantly decrease the residence time of oil through mechanical abrasion and sediment removal.
4. Wind directions and frequencies indicate that an oil spill in Lancaster Sound will have little chance to be blown clear of the shoreline.
5. Shorelines with high physical sensitivity ratings (8 to 10) are rare (6 per cent) indicating that biological sensitivity should be the determinating factor in countermeasure procedures.
6. There are no cleanup techniques unique to arctic environments; existing methods will be applicable throughout the limited open water season.

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APPENDIX I

Summary of the meterological data base used for construction of wind roses on Figure 4

Location Lat. Long.	Height of Anemometer Above sea level (m)	Period of record (July to Oct. unless otherwise specified)	Number of daily Observations	Total Number of Observations	Data Source
Arctic Bay					
73°00'N; 85°18'W	11	1953-1973	Irregular	6714	AES[1]; pers comm. (1980)
78°02'N; 85°09'W	11	1973-1976	Irregular		
Bathurst Bay					
73°24'N; 77°03'W	20 (approx).	Aug. 16-29, 1979	144	1838	Arctic Sciences Ltd. pers. comm. (1980)
Cape Charles Yorke					
73°43'N; 82°45'W	20	Aug. 4 - Sept. 15, 1977	48	2016	Hill et al. (1978) Fenco (1978)
Cape Liverpool					
73°36'N; 78°02'W	15	July 9 - Sept. 30, 1979	24	1961	Petro-Canada pers. comm. (1980)
Clyde					
70°27'N; 68°33'W	10	1953-1976	Irregular	20991	AES; pers. comm. (1980)
Coburg Island					
75°54'N; 79°02'W	3	Sept. 1972 - Sept. 1973	4	1229	AES; pers. comm. (1980)
75°55'N; 79°00'W	3	Sept. 1973 - Sept. 1974			
Cunningham Inlet					
74°08'N; 93°54'W	11 (approx.)	1974-1976	4	792	Taylor (1977) and Taylor, R.B.; pers. comm. (1980)
	25 (approx.)	(except. Sept. 1975)			
Devon Island					
74°40'N; 84°40'W	430 (approx.)	1961-1962	24	846	AES; pers. comm. (1980)
Dundas Harbour					
74°32'N; 82°25'W	5.5	unknown 3 year period	3	1107	Canadian Hydrographic Service (1968)
Philpots Island					
75°54'N; 79°32'W	15 (approx.)	July 11 - Oct. 3, 1979	24	1966	Petro-Canada, pers. comm. (1980)
Pond Inlet					
72°41'N; 77°59'W	4	1940-1954	2	3320	Woodrow (1972)
72°40'N; 78°00'W	59	1975-1976	24	3684	AES, pers. comm. (1980)
Prince Leopold Island					
74°02'N; 90°00'W	274 (approx.)	July - Sept. 1975-1976	2	348	R.B. Taylor, pers. comm. (1980)
Resolute Bay					
74°43'N; 94°59'W	64	1953-1976	8(1953-1957) 8 (1959-1962) 24	55028	AES, pers. comm. (1980)
Rodd Bay					
73°76'N; 90°18'W	12	July 19 - Aug. 8, 1977	96	2016	Hill et al. (1978)
Marine Grid 7	all observations taken at varying altitudes from ships	1946-1973 (primary[2]) 1893-1973 (overall)	Irregular	1557	Data compiled and tabulated by the U.S. National Climatic Data Centre, N.O.A.A. Environmental Data Service Data received from A.E.S. (pers. comm., 1980).
76.3°N; 73.6°W					
Marine Grid 10		1947-1973 (primary) 1903-1973 (overall)	Irregular	1754	
74.5°N; 94.3°W					
Marine Grid 11		1947-1973 (Irregular 1903-1973 (overall)	Irregular	1804	
73.9°N; 83.7°W					
Marine Grid 12		1947-1973 (primary) 1903-1973 (overall)	Irregular	792	
73.9°N; 75.7°W					
Marine Grid 13		1948-1972 (primary) 1898-1972 (overall)	Irregular	3104	
74.7°N; 64.8°W					
Marine Grid 18		1948-1973 (primary) 1946-1973 (overall)	Irregular	1045	
71.6°N; 69.9°W					
Marine Grid 19		1947-1973 (primary) 1910-1973 (overall)	Irregular	995	
71.5°N; 63.3°W					
Marine Grid 23		1948-1973 (primary) 1928-1973 (overall)	Irregular	1022	
68.8°N; 63.6°W					

[1] AES - Atmospheric Environment Service, Environment Canada.
[2] Primary period of record is that period which represents 80% of the total number of recorded observations.

APPENDIX IIA

Range of tides at Resolute and Secondary Ports (Dohler, 1966)

Port	Latitude (N)	Longitude (W)	Mean Tide (m)	Large Tide (m)
Resolute Bay	74°41'	94°54'	1.3	2.1
Rigby Bay	74°33'	90°10'	1.7	2.8
Dundas Harbour	74°31'	82°26'	1.8	2.9
Pisiktarfik Island	72°35'	80°30'	1.5	2.6
Milne Inlet (head)	71°54'	80°51'	1.5	2.7
Koluktoo Bay	72°06'	80°47'	1.5	2.5
Clyde	69°50'	70°22'	0.9	1.4

APPENDIX IIB

Tide data collected by the Geological Survey of Canada

Location	Latitude (N)	Longitude (W)	Period of Record	Mean Tide	Tide Range
Philpots Island	74°50'	79°40'	Aug. 21-25, 1978	1.44	0.83-1.94
South coast Devon Island	74°35'	81°06'	Aug. 29 - Sept. 1, 1978	1.16	0.78-1.51
Borden Peninsula	73°44'	81°35'	Sept. 4-6, 1978	1.58	1.50-1.70
Oliver Sound	72°26'	78°32'	Sept. 11-13, 1978	0.91	0.65-1.09
Scott Inlet	71°14'	71°10'	Sept. 16-17, 1978	1.04	0.98-1.17
Cape Fanshawe	73°34'	77°26'	Aug. 10-18, 1979	1.33	0.51-2.22

APPENDIX IIC

Tidal notes from Pilot of Arctic Canada (C.H.S., 1968) and sailing directions, Arctic Canada (C.H.S., 1978a)

Location	Latitude (N)	Longitude (W)	Spring tide (m)	Neap tide (m)	Tidal currents
Navy Board Inlet	73°13'	80°52'	-	-	Tide rips have been reported in the vicinity of the Wollaston Islands and across the entrance to Navy Board Inlet.
Tay Bay	73°28'	80°43'	Observations over a two-day period in 1946 indicated a tidal range of about 1.7 m.		
Eclipse Sound/Milne Inlet	72°40' 72°20'	78°50' 80°25'	-	-	Winds and strong currents (tidal) drive ice back and forth in western Eclipse Sound and in and out of the outer parts of Milne Inlet.
Pond Inlet	72°41'	77°59'	2.1	0.9	The tidal stream is reported to run westward when flooding and eastward when ebbing at a rate of about 103 cm/s.
Possession Bay	73°30'	77°23'	2.4	1.8	
Cape Adair	71°24'	71°13'	2.6	2.1	
Cape Christian	70°31'	68°18'	2.2	1.7	The tidal stream is reported from 51-103 cm/s., flowing northerly with rising tide and southerly when it is falling.
Patricia Bay	70°25'	68°38'	2.4	-	The tidal stream is reported to be negligible.

APPENDIX III

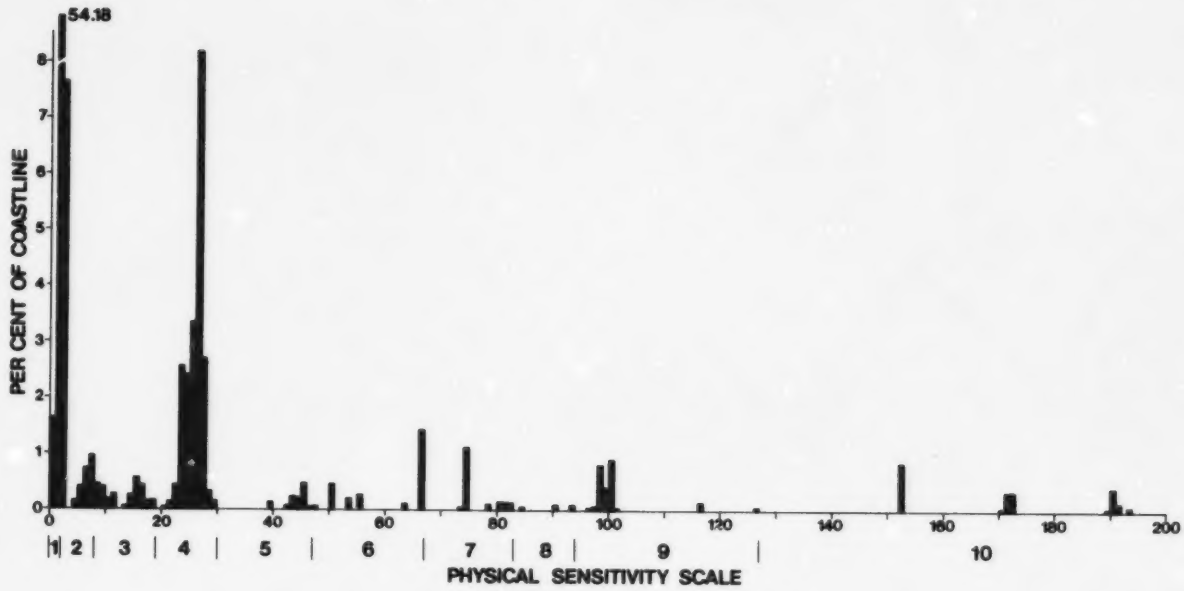
Physical sensitivity value (1 to 193 derived from Table 5	Physical sensitivity category (PSC) 0-10 Table 6	Coastal description (Table 4)	Total length of coastline (4915 km)	Per cent of total coastline
0	0	G	80.2	1.63
1	1	sR	2663.05	54.18
2	2	mR	376.2	7.65
4		mR/pBb	2.7	0.05
5		lR/pBb	3.71	0.08
6		sR/pBc	6.07	0.12
7		sR/cBc	42.11	0.86
8		mR-pBb	22.87	0.47
9		lR-pBb	3.15	0.06
10		mR-pBg	9.19	0.19
11	3	mR-pBc	13.82	0.28
13		mR-cBb	1.93	0.04
		sR-cBs	1.99	0.04
14		sR-cBg	10.63	0.2
		mR-cBs	3.63	0.07
15		mR-cBg	24.81	0.5
		sR-cBc	4.63	0.09
16		mR-cBc	22.06	0.45
17		lR-cBc	6.04	0.12
		sU-cBg	2.67	0.05
18		mU-cBg	8.21	0.17
20		sR:cBb	2.07	0.04
21	4	mR:cBb	6.97	0.14
22		sR:cBg	20.32	0.41
		mR:cBs	2.43	0.05
23		mR-bBb	19.11	0.39
		sR:cBc	38.13	0.78
		mR:cBg	18.44	0.38
		sU:cBb	50.65	1.03
24		lR-bBb	6.11	0.12
		lR:cBg	1.86	0.04
		sU:cBs	34.5	0.70
		mU:cBb	51.84	1.05
		mR:cBc	24.72	0.5
25		mU:cBs	73.68	1.5
		mR-bBg	9.43	0.19
		lR:cBc	1.56	0.03
		sU:cBg	80.6	1.64
26		mU:cBg	260.11	5.29
		sU:cBc	63.1	1.28
		lU:cBs	78.89	1.61
27		lR-bBc	12.11	0.25
		mU:cBc	56.54	1.15
		lU:cBg	64.71	1.32
28		lU:cBc	16.82	0.34
29		lU:bBg	8.46	0.17
39	5	mR:bBb	7.18	0.15

APPENDIX III (cont.)

Physical sensitivity value (1 to 193 derived from Table 5	Physical sensitivity category (PSC) 0-10 Table 6	Coastal description (Table 4)	Total length of coastline (4915 km)	Per cent of total coastline
42		lR:bBg	4.45	0.09
43		mU:bBs	12.13	0.25
44		lU:bBs	9.06	0.18
		mU:bBg	2.51	0.05
45		lU:bBg	24.0	0.49
46		lU:bBc	3.15	0.06
47	6	mR/pBc-nI	3.09	0.06
49		lU-nIg	0.62	0.01
50		mR-pBg-nI	22.86	0.47
53		mR-pBg-nIg	7.41	0.15
		lR-pBb-nIc	2.75	0.06
55		mR-cBg-nI	14.08	0.29
63		mR:cBg-nI	5.72	0.12
66		mU:cBg-nI	70.41	1.43
73	7	sR:nI	3.66	0.07
74		mR:nI	54.5	1.11
78		mR/cBb:nIb	5.54	0.11
80		lU:nIs	6.96	0.14
81		lU:nIg	7.42	0.15
82		lR/pBs:nIc	5.17	0.11
		lU:nIc	1.23	0.03
84	8	mR-pBg:nIs	2.75	0.06
89		mR-cBg:nIs	4.89	0.01
93		lU-cBg:nIs	4.91	0.1
96	9	mR:cBg:nIb	2.45	0.05
97		mU:cBs:nI	3.48	0.07
98		mU:cBg:nI	37.99	0.77
		sU:cBs:nIs	2.48	0.05
99		mU:cBs:nIs	20.24	0.41
100		mU:cBg:nIs	27.15	0.55
		lU:cBs:nIs	17.88	0.36
101		lU:cBg:nIs	2.29	0.05
116		lU:bBs:nI	6.98	0.14
126		lU:bBs-wIs	3.59	0.07
152	10	lU:wIs	42.84	0.87
170		sU:cBs:wIs	3.16	0.06
171		lU:cBg:wI	4.22	0.09
		mU:cBs:wIs	12.33	0.25
172		lU:cBs:wIs	7.41	0.15
		mU:cBg:wIs	9.42	0.19
189		lU:bBg:wI	2.42	0.05
190		lR:bBc:wIg	6.58	0.13
		lU:bBs:wIs	14.17	0.29
191		lU:bBg:wIs	8.12	0.17
193		lU:bBg:wIc	4.56	0.09
Total			4915.2	99.96

APPENDIX IV

Per cent frequency diagram of every coastal description listed in Appendix III showing the divisions of the physical sensitivity categories (PSC) 1 to 10



MAPS NOT

FILMED

CARTES

OMISES